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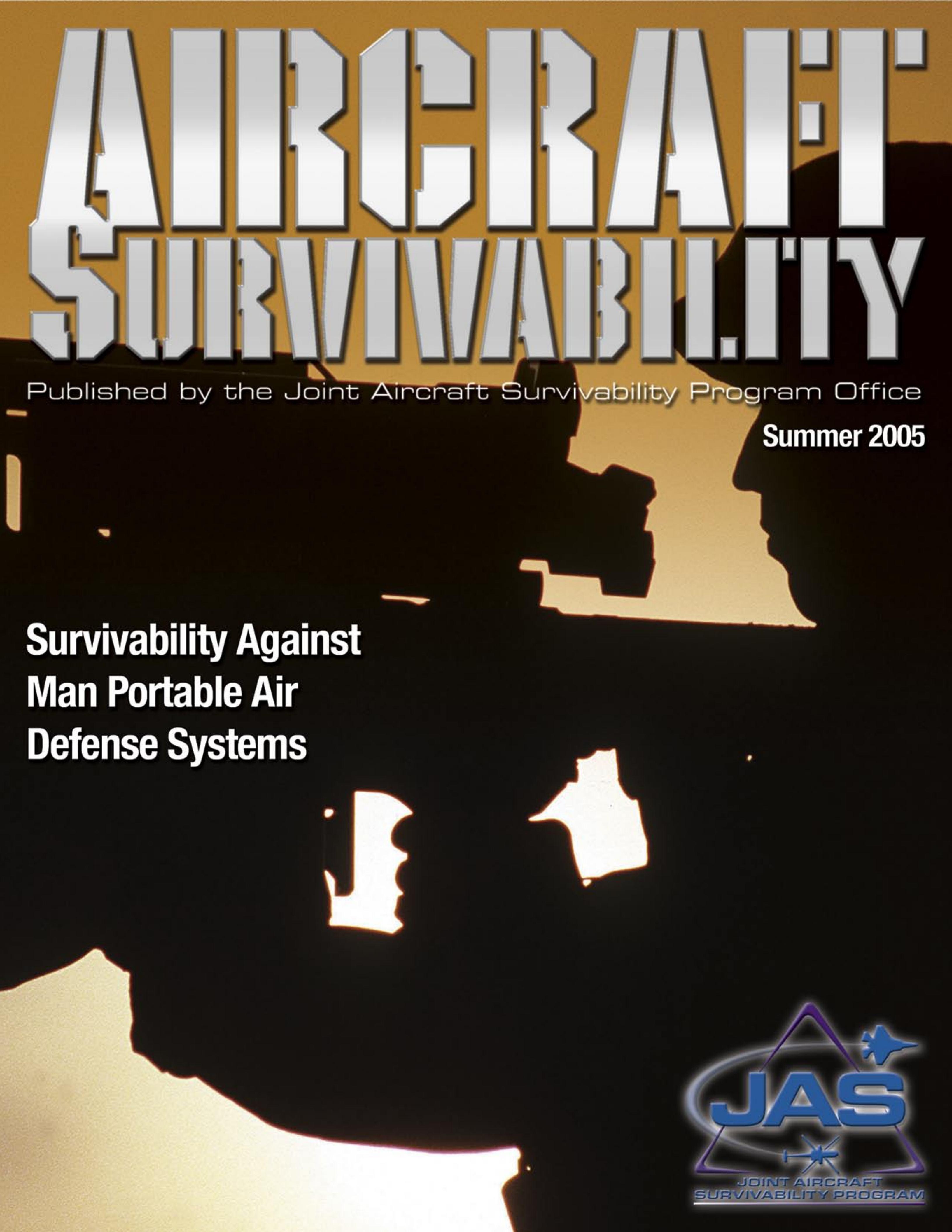

Survivability Against Man Portable Air Defense Systems

JAS
JOINT AIRCRAFT SURVIVABILITY PROGRAM

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News Notes

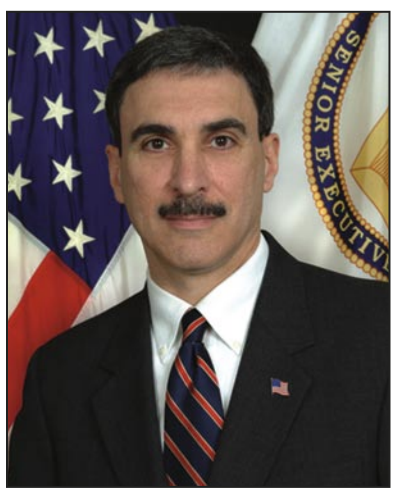
■ *by Mr. Dennis Lindell*

Survivability Pioneer Walt Thompson Passes Away

Mr. Walt Thompson, a nationally and internationally recognized expert in aircraft propulsion system vulnerability and vulnerability reduction, passed away on April 15, 2005. He was 69. Mr. Thompson worked at the US Army Ballistic Research Laboratory, later the US Army Research Laboratory, at Aberdeen Proving Ground for over 30 years until his retirement in 1997. After government service, he worked for the SURVICE Engineering Company until his death.

Mr. Thompson's dedication and tireless efforts improved the survivability of the majority of US combat aircraft engines developed over the past 35 years, and thus, the aircraft using them and their crews. His pioneering analytical and empirical work to determine and reduce turbine engine ballistic vulnerabilities was particularly influential in the development of the T700 engine now used in the multi-service H–60 helicopter series and others. Mr. Thompson was also knowledgeable about threat aircraft propulsion systems' vulnerabilities and associated lethality of US munitions, having performed numerous research studies and controlled-damage and live-fire tests on foreign engines. He was a valued member of many propulsion committees and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME), the Joint Technical Coordinating Group for Aircraft Survivability (JTCG/AS), now the Joint Aircraft Survivability Program (JASP), and the Joint Live Fire Test Program (Aircraft Systems).

Mr. Thompson's passion for acquiring knowledge—more importantly, his special ability to articulate the results of his work and unselfishly share with all who simply had to ask—was second to none. His legacy will surely be the multitude of excellent reports and briefings he generated over the past 40 years in the field of propulsion system survivability. But the deepest loss will be the warm, personal manner in which Mr. Thompson freely shared his knowledge. Many members of the survivability/lethality community grew technically and professionally under his mentorship. He will be greatly missed by all who knew him.



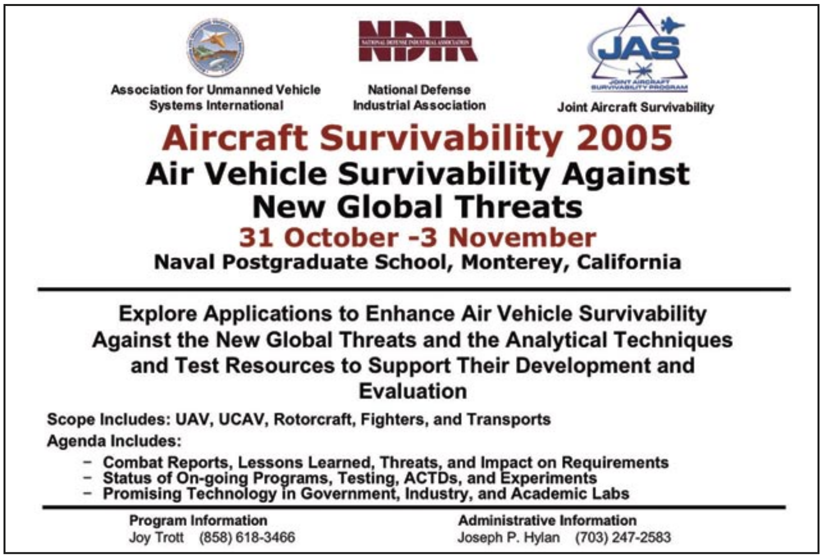
Dr. Paul Tanenbaum named Director of the Survivability/Lethality Analysis Directorate (SLAD)

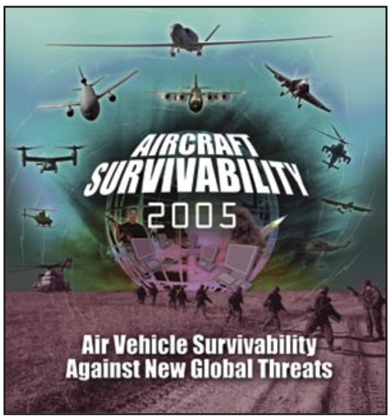
Dr. Paul Tanenbaum has been appointed director of the Survivability/Lethality Analysis Directorate (SLAD) of the US Army Research Laboratorys (ARL). Dr. Tanenbaum is one of the Army's top experts in performing and managing Vulnerability/Lethality (V/L) analyses of armor and anti-armor systems.

Dr. Tanenbaum joined the US Army Ballistic Research Laboratory (BRL), ARL's predecessor, in 1981, after earning a BS degree in Mathematics from the University of Maryland. While at BRL, and later at ARL, he earned his MS in Engineering, and PhD degrees in computer science from The Johns Hopkins University.

During the late 1990's, Dr. Tanenbaum led the Advanced Computer Systems Team and was responsible for developing and maintaining the Army's primary ballistic V/L model, the Modular UNIX-Based Vulnerability Estimation Suite (MUVES). In 2001, he was named chief of the Engineering Analysis Branch. In this position, he oversaw the characterization of vehicle and sub-system vulnerability and the development of physics- and engineering-level ballistic methodology and engineering modeling that support V/L analyses. Since 2003, he has been chief of SLAD's Ballistics and Nuclear, Biological, and Chemical (NBC) Division, where he has directed applied research and analysis in survivability against nuclear, biological, chemical, electronic, and information threats as well as conventional ballistic threats in support of Army acquisition programs. In 2004, Dr. Tanenbaum was a Senior Executive Fellow at Harvard University's John F. Kennedy School of Government.

We extend our sincere congratulations to Dr. Tanenbaum in his new position.





"Air Vehicle Survivability Against New Global Threats"

The National Defense Industrial Association (NDIA) and the Association for Unmanned Vehicle Systems Internationsl (AUVSI) are sponsoring, with the support of the Joint Aircraft Survivability Program, the Under Secretary of Defense, the Assistant Secretary of Defense Networks Information and Integration, the Deputy Director, Operational Test and Evaluation, the Director, Force Structure, Resources and Assessment, the American Institute for Aeronautics and Astronautics, and the Association of Old Crows, the "Air Vehicle Survivability Against New Global Threats" Conference on October 31—November 3, 2005 at the Naval Postgraduate School, Monterey, in California. The deadline for Abstract Submittals was May 30 and is now past, but Awards nominations are due August 1, and the deadline for exhibit space is August 30, 2005.

The conference's theme focuses on exploring applications to enhance air vehicle survivability against the new global threats and the analytical techniques and test resources to support their development and evaluation. The scope includes UAV, UCAV, Rotorcraft, Fighters, and Transports. The agenda includes the following:

- Combat reports, lessons learned, threats, and impact on requirements
- Status of ongoing programs, testing, ACTDs, and experiments
- Promising technology in government, industry, and academic labs

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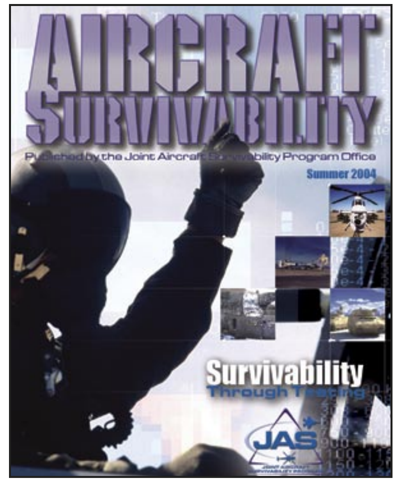
You may also visit http://register.ndia.org/interview/register.ndia?~Brochure~6940 to view or download Call for Presentations, Exhibits, and Award Nominations.

Survivability Journal wins award

The JASPO is pleased to announce that the Summer 2004 issue of the Survivability Journal on Survivability through Testing, received an Award of Distinction, Print Media, from The



Communicator Awards in February 2005. The Communicator Awards is an international competition that recognizes outstanding work in print, video, and audio communications. Entries are judged by industry professionals who look for companies and individuals whose talent exceeds a high standard of excellence and whose work serves as a benchmark for the industry. This award is presented to those projects that exceed industry standards in communicating a message or idea. More than 5,000 entrants from throughout the United States and several foreign countries competed for these awards.

Mr. Joe Jolley was the editor of the Survivability Journal at the time, and Dale Atkinson was the assistant editor. Ms. Christina McNemar from SURVIAC and her Multimedia and Creative Solutions Team created this award-winning issue along with the editors and the authors who wrote the excellent articles. The Multimedia and Creative team members involved were Ms. Christina P. McNemar, Creative Solutions Director; Ms. K. Ahnie Jenkins, Creative Director; Ms. Bryn G. Farrar, Art Director; Ms. Maria M. Candelaria, design, layout, and cover artist; and Ms. Kathy Everett and Mr. Dustin J. Hurt, illustrators. Congratulations to Joe, Dale, Christina and her team, and all the authors who contributed to this issue for a job well done.

To see a listing of all winners of The Communicator Awards, please visit their site http://www.communicator-awards.com/ ■

Large Aircraft Survivability Initiative (LASI)

by Mr. Carter (Ben) Brooks, Mr. Gregory J. Czarnecki, Dr. Christine M. Belcastro, Dr. Celeste M. Belcastro, and Mr. J. Michael Heard

Shoulder-launched missiles, also known as Man-Portable Air Defense Systems (MANPADS), have become a significant threat to civil and military aviation. Because of predictable flight paths, slow speed, and high Infrared (IR) signatures, large aircraft are particularly at risk during takeoff and landing. Encounters with MANPADS threats in Mombassa, Kenya (2002), and Iraq (2003 and 2004) have highlighted the need to assess large aircraft survivability and methods to mitigate MANPADS damage.

The Large Aircraft Survivability Initiative (LASI) is an Air Force initiative that encourages government and industry collaboration to improve commercial and heavy military aircraft survivability to MANPADS and other threats. The LASI team consists of the Air Force 46th Test Wing, NASA, and a number of industry partners. LASI planning began in 2002 with the identification of five data voids relative to large aircraft survivability:

- **Lack of high-fidelity IR signatures of large commercial aircraft**—These IR signatures are required to perform MANPADS hit-point predictions, which are used by the vulnerability community to focus Modeling and Simulation (M&S) vulnerability assessments and to select meaningful shotlines for testing.
- **Lack of information concerning large aircraft vulnerability to MANPADS**—Test data are needed to validate aircraft vulnerability assessments used for operational risk assessments. A combination of test and validated M&S data is needed to support national investment decisions concerning IR countermeasures.
- **Lack of information concerning the safety of flight and recoverability of commercial aircraft damaged by a MANPADS strike**—Accurate assessments of MANPADS damage are needed to develop damage mitigation strategies (including damage adaptive control system technologies) that provide improved recoverability and, in the event of a hit, insure continued safety of flight.
- **Lack of fire-protection technologies that are compatible with commercial aviation**—Affordable, low-weight fire-protection concepts are required to insure that hits from a variety of munitions do not result in aircraft kills caused by onboard fires.
- **Lack of information concerning commercial aircraft vulnerability to Electromagnetic Effects (EME)**—Test data are needed for operational risk assessments and to support national investment decisions concerning shielding and other countermeasures.

Figure 1. MANPADS missile damage sustained by Airbus A300, November 22, 2003

The LASI team addresses all five areas of deficiency. Under partial sponsorship by the Joint Aircraft Survivability Program (JASP), IR signatures have been collected by the 46th Test Wing and NASA on three large aircraft, with other signature tests planned. Preparations for assessing large aircraft vulnerability to MANPADS are now under way and include test-asset acquisition, improvements to missile-launch devices, test-plan development, and pre-test prediction analyses. These vulnerability assessment activities, co-sponsored by the Joint Live Fire (JLF) program and JASP, are being conducted by the 46th Test Wing's Aerospace Survivability and Safety Flight at Wright-Patterson Air Force Base (AFB), Fairborn, Ohio, and the 46th Operations Group at Eglin AFB. Wind-tunnel tests are planned at NASA Langley to develop models of aircraft response to MANPADS damage. Results from these tests will be used to analyze the safety of aircraft flight relative to incurred MANPADS damage and to develop

control-accommodation methods for on-board mitigation of MANPADS damage. Lastly, test planning and test-asset collection have been initiated in support of fire-prediction methodologies and EME protection.

In summary, with JASPO and JLF support, the LASI team has begun to address a number of data voids concerning large aircraft survivability in a threat environment. These data voids must be resolved to define and evaluate alternative solutions to improve survivability. LASI results will be used to promote safety-of-flight while supporting aircraft vulnerability assessments, operational risk assessments, and Infrared Countermeasures (IRCM) investment decisions. The value of this information to the Department of Defense (DoD), Department of Homeland Security, the aviation industry, and the nation's economy will prove immeasurable. ■

Mr. Carter (Ben) Brooks graduated from Auburn University with a BS degree in Aerospace Engineering. Mr. Brooks has been employed as a flight-test engineer for the Boeing Commercial Airplane Group in Seattle, Washington, and for the Air Force Flight Test Center at Edwards AFB, Rosamond, California. After moving to Eglin AFB, he became a lead engineer at the McKinley Climatic Laboratory, where he conducted environmental testing on full-scale weapons systems for the Air Force and other US Department of Defense agencies. While at the Climatic Lab, Mr. Brooks was Air Force project engineer for the renovation of the 50-year-old facility. His career broadened as he joined the staff of the 46th Test Wing to conduct long-range planning for range systems and advance test and evaluation instrumentation. For the last two years, he has been a Test Programming Engineer in the Air Force Live Fire office, involved in assessing the survivability of aircraft. He may be reached by e-mail at carter.brooks@eglin.af.mil.

Mr. J. Michael Heard received a BS in Aerospace Engineering and a MS degree in Engineering Mechanics, both from the University of Alabama, Tuscaloosa, Alabama. He is a civilian staff member of the 46th Test Wing Munitions Test Division and may be reached at james.heard@eglin.af.mil.

The DoD is interested in insuring the survivability of large military aircraft, such as the C–17, and has a long history of research and testing of military aircraft in support of Live Fire Test & Evaluation (LFT&E) mandated by Title 10. With DoD's increased use of commercial derivatives for military applications and of Civil Reserve Air Fleet (CRAF) vehicles for transport of personnel and materials, the Department's interest extends to the commercial fleet. In support of these interests, the 46th Test Wing provides a national capability for T&E of offensive and defensive weapon systems at Eglin; Wright-Patterson; Hanscom AFB, Bedford, Massachusetts; and Holloman AFB, Alamogordo, New Mexico. The 46th Operations Group, Munitions Test Division, has the mission to plan and execute LFT&E to demonstrate the survivability of military aircraft and the lethality of weapons. The Air Force's 46th Test Wing has the facilities and people to aid the nation and the world in addressing the MANPADS threat to civil aviation.

NASA has a long history of delivering breakthrough technologies that have enabled the US to lead the aerospace world. NASA works on technologies beyond the risk level and return-on-investment time frame of US industry and is uniquely able to study and develop issues and technologies with a long-term, system-wide perspective. The NASA Aviation Safety and Security Program, part of NASA's Aeronautics Research Mission Directorate, is developing technologies to address safety and security needs in future air transportation. MANPADS missiles have been identified as a significant security threat to commercial transport aircraft. It is estimated that there are thousands of MANPADS missiles in circulation, and they are becoming increasingly sophisticated. The goal of Damage Adaptive Control Systems (DACS) is to mitigate the in-flight safety and security risk of terrorist threats to both aircraft and the public by improving survivability from vehicle damage caused by MANPADS and other sources of malicious activity. DACS development is a collaboration between four NASA facilities—Langley Research Center in Hampton, Virginia; Glenn Research Center in Cleveland, Ohio; Ames Research Center in Mountain View, California; and Dryden Flight Research Center in Edwards, California—the US Air Force, and industry. Fire protection technologies are being developed at NASA Glenn, and EME protection technologies are being developed at NASA Langley—both in collaboration with the US Air Force and industry.

NASA's long-range Research and Technology (R&T) capabilities provide the means to implement new security products for civilian aviation that will contribute to national security needs.

Infrared (IR) Signature Measurements of Large Airplanes

■ *by Mr. Carter (Ben) Brooks, Dr. Christine M. Belcastro, Dr. Celeste M. Belcastro, and Mr. John F. Carter*

What components of a large airplane are likely to be hit by a Man-Portable Air Defense (MANPADS) missile, and what is the expected hit-point distribution? Virtually all MANPADS proliferated throughout the world use Infrared (IR) seekers to guide missiles to their intended targets. Large Aircraft Survivability Initiative (LASI) planning activities have already highlighted the lack of high-fidelity IR signatures, which are needed for MANPADS hit-point predictions using Hardware-In-The-Loop (HITL) simulation techniques. In HITL runs, seeker heads from MANPADS missiles are mounted on motion simulators, and the seeker guides a "missile" toward a computer-generated IR image of a target airplane from "acquisition" to "impact." The location of where the missile would have hit can easily be determined by recording the missile's flight path. Hundreds of engagements can be run in this manner, thereby building a statistical database, over various engagement scenarios, of where a missile could hit its target.

The Guided Weapons Evaluation Facility (GWEF) at Eglin Air Force Base (AFB), Valparaiso, Florida, has the facilities to perform these HITL engagements. The real-time target IR image used is typically derived from a Spectral and In-Band Radiometric Imaging of Targets and Scenes (SPIRITS) model of the target airplane. The Air Force Research Laboratory (AFRL) at Hanscom AFB, Bedford, Massachusetts, has the expertise to measure the actual IR signature of an airplane of interest, and, using this data, can create SPIRITS models that are validated by the Joint Army Navy NASA Air Force (JANNAF). Over the years, AFRL has collected data on a wide range of military airplanes and maintains a database of SPIRITS models.

AFRL uses the Flying Infrared Signature Technology Aircraft (FISTA) as the airborne IR data-collection platform. The FISTA is a KC–135E tanker, modified with two rows of 12.5 inches diameter windows on the right side of the fuselage (see Figure 1 on page 9). The airplane has internal "eyeball" mounts for over 10 different measurement systems and 15 racks of associated electronic and control equipment (see Figure 2 on page 9). IR imagery equipment can be inserted into the mounts for nose, tail, side, top, and bottom viewing of the target aircraft.

In the summer of 2004, LASI partners, with support from the Joint Aircraft Survivability Program Office (JASPO), collected the IR signatures of three Boeing aircraft: the 737, the 747, and the 757. All these airplane types have derivatives in both US Air Force and US Navy inventories and are used extensively throughout the world for commercial airline and airborne freight operations. Many commercial 747's support the military as part of the Civil Reserve Air Fleet (CRAF), hauling military personnel and supplies worldwide. Through the LASI partnership, the Navy provided a C–40A Clipper, a derivative of the 737–700, and NASA contributed their 757 research airplane (see Figure 3 on page 9). The signature-measurement missions were typically flown over a 300 mile long racetrack pattern. High-altitude test points were flown at about 23,000 feet at 0.75–0.80 mach, and low-altitude points were flown at about 6,000 feet at 220–260 knots. Usually, the target airplane was the formation lead, and the FISTA maneuvered around the lead airplane to record signature data.

The following list summarizes the IR data collected:

- Extensive geometric mapping of a single-engine IR signature
- Variations of engine signature with a power setting at two altitudes and four geometries
- Total target-signature measurements at nose, side, and tail aspects in Bands 1 and 4
- Plume spatial-radiance-distribution maps as a function of power setting
- High-speed plume imagery (1157 Hz) capturing turbulent-flow detail
- Extensive database of specular and diffuse sunglints off the target features
- Thermal imagery showing hot vents and scars on the target
- Aircraft landing-and operating-light signatures
- Results of in-flight engine shutdown to measure how quickly the hot parts of an engine can cool down to ambient temperatures
- IR signatures of five landing and takeoff simulations measured with stable geometry—the aircraft went through a full landing and takeoff sequence

- IR measurements of the aircraft de-ice operation at high altitude
- Spectral measurements of sunglints, engine operation, and plume emissions
- Polarized IR measurements of sun and engine reflections off the fuselage

Over the next several months, the collected data will be reviewed, and selections of the data will be radiometrically calibrated and analyzed to provide inputs and validation for the construction of the SPIRITS model. Once the model is complete, the HITL work at GWEF can begin. ■

Dr. Celeste M. Belcastro received a BS in Electrical Engineering, 1980, and a MS in Engineering, 1986, both from Old Dominion University, Norfolk, Virginia. She received a PhD degree in Electrical Engineering in December 1994 from Drexel University, Philadelphia, Pennsylvania. Dr. Belcastro has been a research engineer at NASA Langley Research Center, Hampton, Virginia, since June 1980. She is a Senior Research Engineer and Technical Manager for the NASA Aviation Safety & Security Program (AvSSP) and conducts research in Vehicle Health Management and Flight-Critical Systems Design. She is Deputy Technical Manager for AvSSP Damage-Adaptive Control Systems and Technical Manager in the NASA Vehicle Systems Program for Onboard Prognostics and Failure Mitigation. Her research interests include malfunction effects in complex integrated systems caused by electromagnetic disturbances and ionizing radiation; state estimation and distributed-fault detection with data fusion; real-time performance monitoring and assessment; failure-accommodation techniques for highly reliable flight systems; and validation of complex, integrated, adaptive, embedded systems for flight-critical aerospace applications. She may be reached by e-mail at celeste.m.Belcastro@larc.nasa.gov.

Figure 1. KC–135E/FISTA

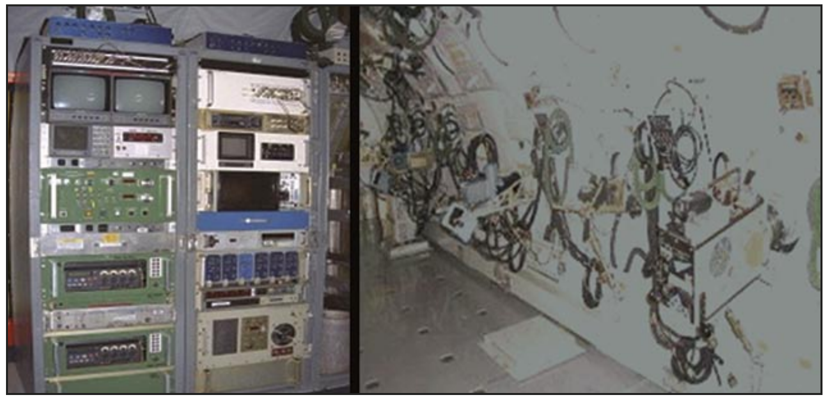


Figure 2. FISTA On-Board equipment and instrumentation

Mr. John F. Carter is currently a project manager for intelligent flight-control systems at NASA Dryden Flight Research Center, at Edwards Air Force Base, Rosamond, California. He has worked at NASA for 15 years; for three of those years, he has been an Air Force engineer. He has conducted numerous design projects in handling qualities and controls for the B–1B bomber program, F–18 High Alpha Research Vehicle (HARV), the F–15 Advanced Control Technologies for Integrated Vehicles (ACTIVE) project, the F–18 Active Aeroelastic Wing (AAW) project, the F–15 Intelligent Flight-Control System project, the Convair CV990 project, and the X–43 Hyper-X project. Mr. Carter holds a BS in Mechanical Engineering from San Diego State University and a MS in Mechanical Engineering from Fresno State University, California. He has authored over 20 publications on all aspects of controls and handling qualities and has received numerous awards, such as the Silver Snoopy award in support of the Space Shuttle Program and the NASA Ames (Research Center) award for outstanding engineering. He may be reached through e-mail at john.f.carter@nasa.gov.

Mr. Carter (Ben) Brooks, biography can be found on page 7.

Figure 3. Atlas Air 747–400F (top), Navy C–40A Clipper (middle), NASA 757 (bottom)

Figure 4. 747 Nose Aspect IR Imagery

Large Aircraft Vulnerability to Man-Portable Air Defense Systems

(MANPADS)

■ *Mr. Gregory Czamecki, Mr. Robert Yelverton, and Mr. Carter (Ben) Brooks*

Infrared (IR) Man-Portable Air Defense Systems (MANPADS) missiles have been a threat to military operations since the early 1970s. In recent years, terrorist groups have gained an interest in these missile systems because of their ready availability, low cost, and fire-and-forget simplicity. The incidents of September 11, 2001, began a public debate on the possibilities of a terrorist threat associated with these weapons, but the attempted shoot-down of an Israeli airliner in 2002 demonstrated that MANPADS are a clear threat to commercial aviation. In 2003, the US Department of Homeland Security (DHS) began studying a transition of military Infrared Countermeasures (IRCM) technology to commercial transport aircraft. The cost of implementing IRCM hardware throughout the civil sector and the associated annual life-cycle costs are estimated to be quite significant. While investments of this magnitude may be necessary to avert both loss of life and economic disaster, fundamental questions remain unanswered: What is the vulnerability of large aircraft to a MANPADS impact? What components are likely to be hit, and what is the expected hit-point distribution? Are aircraft vulnerability models capable of predicting MANPADS damage? How much damage will be sustained given a hit to an engine, pylon, wing, empennage, or fuselage? How does the damage affect engine operation and thrust? What is the expected effect of damage on aircraft safety-of-flight? Will a hit result in an aircraft kill? If so, what is the kill mechanism? What methods can be applied to both reduce vulnerability and to prevent a kill mechanism from occurring?

The Large Aircraft Survivability Initiative (LASI), with the sponsorship of the Joint Aircraft Survivability Program (JASP) and the Joint Live Fire (JLF) Program, has begun to provide answers to these and other questions. The LASI team is uniquely positioned to provide high-quality, relevant information to decision makers because of its collective years of experience in assessing aircraft vulnerability, understanding synergisms and differences between military and commercial aircraft, and providing solutions to reduce vulnerability.

LASI's Vulnerability Assessment Working Group, consisting of the 46th Test Wing; NASA; General Electric Aircraft Engines (GEAE); RHAMM Technologies; SURVICE Engineering; and Skyward, Ltd., will use a model-test-model approach to evaluate the vulnerability of large aircraft structure and engines to the MANPADS threat. Using probabilistic shotlines and hit points, planned tests will begin with MANPADS shots into non-operational Pratt and Whitney JT9D engines and culminate with similar shots into operating GEAE CF6 engines. The tests will be performed at the Aerospace Vehicle Survivability Facility at Wright-Patterson Air Force Base (AFB), Ohio, and at Eglin AFB, Florida. Coordinated with this engine-test activity are two modeling efforts. In the first, GEAE and RHAMM Technologies will work together to join an existing high-fidelity LS DYNA 3–D missile model with a GEAE engine model for the purpose of predicting damage. The second modeling effort involves NASA's translation of engine damage—change of thrust and collateral damage to the surrounding structure—into meaningful safety-of-flight terms. Progress to date includes developing a precision method of MANPADS launch, preparing a MANPADS *vs.* engines test plan, and acquiring engine test assets. Engine-MANPADS testing will begin in late 2005 and conclude in 2006. In conjunction with these tests, the 46th Test Wing has created a controlled-access area that will house hardware that has been operationally damaged to use in direct comparison with LASI-generated damage predictions and test results.

Figure 1. Planned MANPADS tests on engines, structure, and control surfaces

LASI's assessment of aircraft vulnerability continues with planned MANPADS shots into pylons, wings, empennage, and (potentially) fuselage structure. (reference Figure 1) Damage and the potential for sustained fire will be assessed to support the credibility of vulnerability assessment predictions for evaluations of operational risk. NASA will also evaluate damage to flight-controls systems and translate the overall damage into safety-of-flight implications. Progress relative to this MANPADS evaluation of transport aircraft structures and flight controls includes identifying B–747 and B–757 test assets.

The B–747 was selected based on its use as the primary Civil Reserve Air Fleet (CRAF) carrier. The B–757 was selected as representative of the two-engine, wing-mounted aircraft that constitutes approximately 66 percent of the commercial domestic fleet. NASA has also developed, as part

continued on page 17

Damage Adaptive Control Systems (DACS) for Large Aircraft

■ *by Dr. Christine M. Belcastro and Dr. Celeste M. Belcastro*

Man-Portable Air Defense System (MANPADS) missiles have been identified as a significant security threat to commercial transport aircraft. Thousands of MANPADS missiles are estimated to be in circulation and they are becoming increasingly sophisticated, as evidenced for example by their Infrared (IR) guidance systems. These systems enable a missile to lock onto a targeted aircraft, and additional circuitry allows the missile to divert from the IR target before impact to broaden the scope of the resulting damage. The most recent MANPADS missile attack against a large commercial transport aircraft occurred in November 2003 and involved an A300 cargo carrier. The MANPADS threat is therefore of high interest to the Department of Homeland Security (DHS). The DHS currently sponsors the development of countermeasure systems, based on existing military technologies, that can be transitioned for use on commercial transports. However, these systems will be very expensive and are therefore not expected to be deployed on all commercial transports. Moreover, no countermeasure system is ever 100 percent effective—particularly in light of the increased sophistication of MANPADS' missile circuitry to include counter-countermeasure technologies. The United States Air Force (USAF) is particularly interested in the MANPADS threat for two reasons: it uses commercial transports in its Civil Reserve Air Fleet (CRAF), and it applies commercial-aircraft derivatives in its military fleet. Determining the vulnerabilities of large transport aircraft to MANPADS is the primary focus of the USAF's Large Aircraft Survivability Initiative (LASI).

Technologies to defend against a MANPADS attack can be separated into three categories:

- Limit an attack's occurrence and damage through defensive technologies.
- Prevent the success of an attack through proactive technologies.
- Mitigate the effects of an attack through recovery and survival technologies.

These are illustrated in Figure 1 (see page 12).

The technologies of Damage Adaptive Control Systems (DACS) fall into the third category and are currently in development by NASA under its Aviation Safety and Security Program (AvSSP) as part of NASA's Aeronautics Mission Directorate. This effort is coordinated with the USAF as part of LASI to assist in determining the vulnerability and survivability of large transport aircraft to MANPADS damage. NASA's role within LASI is to translate relevant damage scenarios (defined by the USAF based on MANPADS hit-point predictions) to safety-of-flight and recoverability implications.

DACS provides a unique focus on mitigating MANPADS' strike damage because it addresses research issues that are not investigated by the Department of Defense (DoD), industry, academia, or any other government agencies. The goal of DACS is to mitigate the in-flight safety and security risk of terrorist threats to an aircraft and the public by improving survivability from vehicle damage caused by MANPADS and other sources of malicious damage.

The objectives of DACS research are to advance the state of knowledge by focusing on the following areas:

- Characterizing and modeling MANPADS-level aircraft damage including mathematical modeling, simulation, and damage emulation for experimental testing;
- Determining safety-of-flight effects and recoverability (*e.g.*, impacts on handling qualities and probability of recovery) for MANPADS-level damage relative to various vehicle configurations and flight scenarios;
- Developing integrated damage-adaptive control-system technologies, including damage detection and identification, control recovery and reconfiguration, and trajectory and landing guidance for in-flight damage accommodation and safe landing of a damaged vehicle.

Research issues addressed by DACS are MANPADS damage-response modeling, safety of aircraft flight relative to MANPADS damage, and control accommodation for onboard mitigation of MANPADS damage. Specific technical challenges and questions addressed by DACS for each of these issues include the following:

MANPADS Damage Modeling

- What level of modeling, simulation, and experimental test-emulation fidelity is required to accurately and adequately characterize MANPADS-level damage, and how can this damage be characterized in a multidisciplinary sense?

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- Aerodynamics
- Engine
- Airframe structure
- System components

- What are the aerodynamic, engine, and structural coupling issues that need to be addressed?

Safety-of-Flight Relative to MANPADS Damage

- What is the recovery capability of various commercial transport configurations?
- What are the impacts on vehicle dynamics (including loss of stability and control) under various flight conditions and scenarios?
- What level of damage can be sustained by various vehicle configurations and under various flight conditions and scenarios and still be recoverable?

Onboard Mitigation of MANPADS Damage

- How can integrated damage adaptive control system technologies (including damage detection and identification, control recovery and reconfiguration, and trajectory and landing guidance) be developed to mitigate the effects of a MANPADS strike (or other damage source) and to effect a safe landing?
  - Level of improvement in the probability of recovery
  - Technologies that need to be developed
- What are the integrated flight, propulsion, and structural control issues relative to adaptive control of a damaged aircraft?
- What issues arise when implementing integrated DACS technologies into commercial aircraft?
  - Fly-by-Wire (FBW)/ non-FBW aircraft
  - Crew and vehicle interactions
  - How can integrated damage adaptive control system technologies be formally validated and verified for effective and safe operation to enable technology transition (*i.e.*, commercialization and certification)?

The technical approach for investigating these research issues is illustrated in Figure 2 (see page 13).

As shown in Figure 2, DACS provides an integrated approach to MANPADS damage modeling, safety-of-flight assessment, and damage mitigation. Damage-modeling requirements and data will be generated for aerodynamic properties, engine, airframe, and vehicle components. Enhanced flight simulations and damage-emulation strategies will be developed using these damage models and data. An assessment of MANPADS damage effects on aircraft safety-of-flight and recovery capability will be conducted. Factors to be addressed in the study will include the capability and probability of vehicle recovery with corresponding sustainable damage given the vehicle configuration, dynamic effects of the damage, and flight scenarios. The enhanced flight simulations with damage models will be used in this study. Technologies for MANPADS mitigation will also be developed and include methods for damage detection and identification, adaptive-control recovery and reconfiguration, adaptive engine control, and trajectory and landing guidance. These technologies will be integrated and validated using the following:

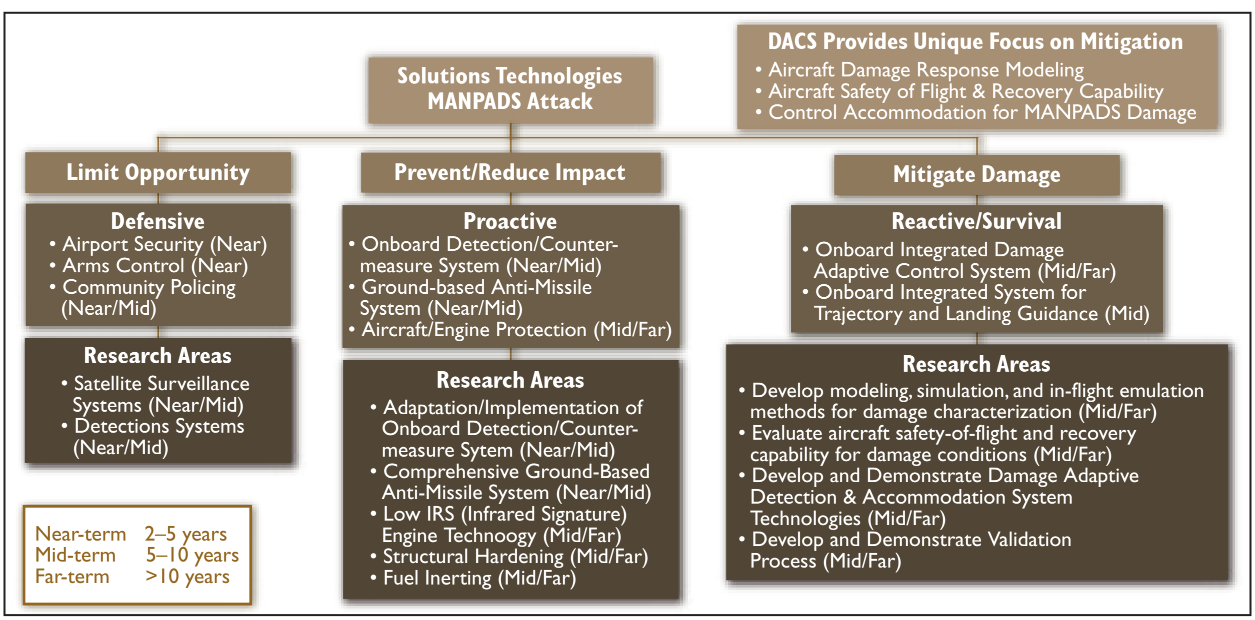


Figure 1. Technologies to defend against a MANPADS attack

- Analysis methods developed in parallel with the technologies;
- Laboratory experiments in engine-test facilities at NASA Glenn Research Center; the Structures Facilities and the Systems and Airframe Failure Emulation Testing and Integration (SAFETI) Laboratory at NASA Langley Research Center; and piloted simulation facilities at Langley, NASA Dryden Flight Research Center, and NASA Ames Research Center;
- Sub-scale flight tests at Langley using the Airborne Subscale Transport Aircraft Research (AirSTAR) capability; and
- Full-scale flight tests at Dryden using the C–17 aircraft, and at Langley using the 757 Airborne Research Integrated Experiments System (ARIES) aircraft.

In summary, DACS technologies are being developed by NASA to provide a last line of defense against vehicle damage posed by terrorist threats such as MANPADS. DACS damage-modeling and simulation technologies will benefit the Department of Homeland Security (DHS) and the USAF in assessing the MANPADS threat to current commercial and military transport aircraft. DACS mitigation technologies will be evaluated for their effectiveness in improving the recoverability (and hence the survivability) of transport aircraft under MANPADS damage. These mitigation technologies will also be applicable to other sources of damage and will increase the safety and security of future commercial and military transport aircraft. ■

Dr. Christine M. Belcastro received a BS in Electrical Engineering in May 1980 and a MS degree in Engineering in May 1986, both from Old Dominion University, Norfolk, Virginia. She received a PhD degree in Electrical Engineering in December 1994 from Drexel University, Philadelphia, Pennsylvania. Dr. Belcastro has been a research engineer at the NASA Langley Research Center since June 1980. She is a Senior Research Engineer and Technical Manager for the NASA Aviation Safety and Security Program (AvSSP) and conducts research in Control Upset Prevention and Recovery and in Damage Adaptive Control Systems. Her research interests include uncertainty modeling of nonlinear parameter-dependent systems for robust control analysis and design; robust adaptive and reconfigurable control for fault tolerance and failure and damage accommodation under adverse operating conditions; recovery from loss-of-control conditions; and the validation of complex, integrated, adaptive detection and control systems for flight-critical aerospace applications.

Dr. Celeste M. Belcastro's biography can be found on page 9.

Figure 2. DACS technical approach

Ms. Kellie Unsworth

Excellence in Survivability

by Mr. Malcom Dinning

The Joint Aircraft Survivability Program (JASP) is pleased to recognize Ms. Kellie Unsworth for Excellence in Survivability. Ms. Unsworth is the US Army's Aviation Applied Technology Division (AATD) program manager for the quick-reaction capability AH–64A/D AN/AAR–57(V)3 Common Missile Warning System (CMWS)/Improved Countermeasure Dispenser (ICMD) A-kit development and integration. The CMWS system uses ultraviolet missile detectors coupled with an electronic control unit and ALE–47 sequencers to control improved smart dispensers for flares and chaff. This program is using AATD's Rapid Prototyping capability to design, fabricate, integrate, demonstrate, and produce limited rate of production A-kits within 12 months of program start to meet the Apache deployment schedule for OEF–4/OIF–7. Functional testing of this system will begin in May.

Ms. Unsworth graduated in 1986 from Swarthmore College with a degree in electrical engineering. After a short stint with the Newport News Shipyard, Virginia, Kellie joined the AATD in 1987. AATD is the Army's primary lab for developing and demonstrating rotorcraft systems Science and Technologies (S&T). Kellie accepted a position with the Safety and Survivability Division where she quickly established herself as a lead technologist in rotorcraft signatures and susceptibility to ground-based threat systems.

Kellie's initial responsibilities focused on improving the understanding of rotorcraft dynamic Radar Cross Section (RCS) and the tactical threat-engagement performance of low-altitude rotorcraft targets. She worked closely with Georgia Institute of Technology on Modeling and Simulation (M&S) tools to assess dynamic RCS levels vs. threat detection and tracking performance to help define future Army requirements. During this time, she also led an effort at White Sands Missile Range, New Mexico, to determine nuclear blast and Electromagnetic Pulse (EMP) effects on rotorcraft systems through extensive, full-scale testing using conventional explosive simulations.

In 1990, Kellie was selected as a principal member of the Light Helicopter Experimental (LHX) (Comanche) Sole Source Selection Board, where she was responsible for evaluating and assessing rotorcraft RCS and susceptibility to threat radar systems. Kellie devoted nearly a year of extended Temporary Duty (TDY) and 70 hour weeks to help the Army select the contractor team to develop and build the Comanche scout light-attack aircraft. During this assignment, it became apparent that government and industry did not share a common understanding of rotorcraft signatures and threat-system effectiveness. With support from the Missile and Space Intelligence Center, Redstone Arsenal, Alabama, many new techniques and M&S refinements were developed in real-time during the Comanche Board to provide credible and validated tools to assess the merits of the two competing designs. Kellie was instrumental in this process.

Shortly after the Comanche Board, Kellie was assigned as project engineer on an extended test program at Eglin Air Force Base (AFB), Valparaiso, Florida, to characterize tactical radar performance against low-altitude rotorcraft targets. This program measured the capability of several tactical threat radars to detect and accurately track Apache, Blackhawk, and Kiowa aircraft ingressing at various altitudes, both over water and over land. Beyond characterizing the performance of these threats against blue-force aircraft, this program also demonstrated the significance of multi-path and structured clutter effects on the cueing accuracy of detection and track radar. Following this test program, Kellie led an effort to increase the resolution of measured rotorcraft dynamic RCS. Sampling rate limitations on many instrumentation radars designed to measure static, fixed-wing targets or relatively slow-moving, in-flight measurements prevented the Army from fully characterizing RCS to the full spectral extent of the rotor-blade signatures, main and tail. Pulse Doppler and Moving Target Indicator (MTI) radar signal-processing logic is designed to extract a moving target from essentially non-moving clutter backgrounds. Rotor blades, with their relatively high rotation rates, present a broad spectrum of Doppler-shifted backscatter energy. Predicting the ability of threat radars to detect and track this energy requires that the full dynamic, or spectral, signature be characterized.

Kellie worked in the test facility of the Naval Air Weapons Station, Point Mugu, California, and successfully measured the Army's fleet aircraft in-flight up to the full spectral limit of the rotor tips. With improved dynamic RCS data, Kellie focused on continuing to improve the M&S tools used to predict radar detection

and track performance. Working with Boeing Seattle, Kellie led an effort to extend high-altitude, fixed-wing radar models to accurately predict low-altitude, rotary-wing performance. This model was then successfully correlated against measured data from the Eglin test.

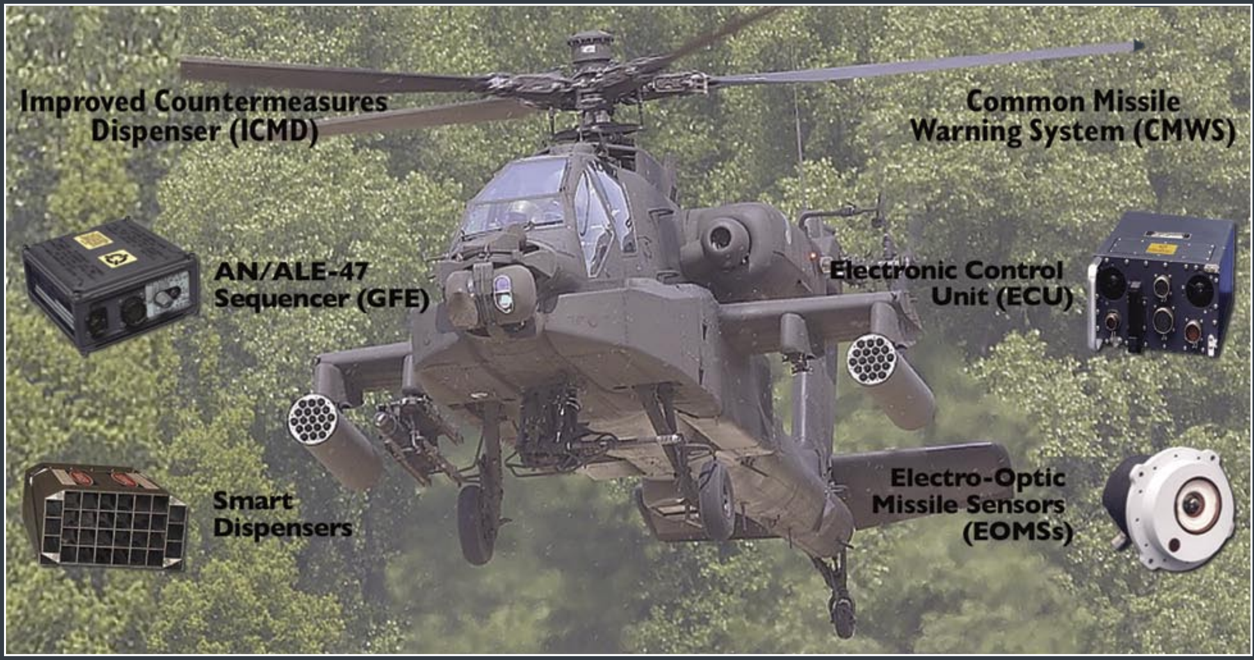
More recently, her activities have focused on Infrared (IR) signatures of rotorcraft and on developing innovative new technologies to reduce them. Kellie led an effort in 1998 to develop an advanced, multi-spectral coating system, initially for the Comanche program, that was later modified for the current Army fleet. This effort combined the requirements for separate primer, top-coat, and anti-static coatings into a single coating system and significant reductions in Band I and IV IR signatures. She was later project engineer on the development of super-lightweight thermal insulation. Under this program, Kellie explored the use of silica-based aerogel materials to reduce the areal density of insulation blankets by 50 percent below that of current state-of-the-art, Commercial-Off-The-Shelf (COTS) insulation materials.

In 2000, Kellie was assigned as project engineer on the next-generation Adaptive Infrared Suppressor system. The objective of this suppressor program was to develop innovative ejector and ducting techniques to reduce the engine-exhaust thermal signature by 75 percent below that of current Apache and Blackhawk IR suppressors. A secondary objective was to reduce the turbine back-pressure effects of traditional suppressor-flow baffles that cause engine power loss. Working with Allied Aerospace, Inc., Kellie spent 18 months optimizing exhaust ejector and nozzle components to achieve extremely high pumping efficiencies in a lightweight, low-restriction system. Design of thermal barrier and convective flow control resulted in a measured 76 percent reduction of the engine-exhaust IR signature relative to the existing Apache IR suppressor system. Back-pressure penalties associated with the suppressor were reduced from 4.2 percent for the current system to 1.6 percent, resulting in a 2.6 percent performance buy-back for the Apache. This suppressor is currently undergoing flight testing on an Apache at AATD.

Kellie is supported by Phil, her husband of 16 years, and her children, Caitlyn and Luke. Life beyond work includes shuttling children to various sporting events and school activities. In her free time, Kellie is active in church and community activities and enjoys running. She lives in Suffolk, Virginia.

It is with great pleasure the JASPO honors Ms. Kellie Unsworth for her Excellence in Survivability contributions to the JASPO, the survivability discipline, and the warfighter. ■

Mr. Malcolm Dinning is the Survivability Management Team Leader at AATD, Fort. Eustis, Virginia, where he is responsible for assessing the Army fleet's current and susceptibility requirements and directing signature-management Tech Base activities to meet those requirements. Mr. Dinning has over 24 years experience in helicopter and tilt-rotor preliminary design, aerodynamics, and survivability in positions with McDonnell Douglas and the Army. He is currently the survivability lead for rotorcraft S&T at the Aviation and Missile's Research, Development and Engineering Center (RDEC). He received a BS degree in Aeronautical Engineering from California Polytechnic State University.



Fuel Tank Explosion Protection (FTEP) for Large Aircraft

Mr. Robert C. McKnight and Mr. Martin L. Lentz

The proliferation of shoulder-fired Man-Portable Air Defense Systems (MANPADS) has long been a recognized threat against civil passenger aircraft.[1,2] On-aircraft countermeasures can confuse missile-guidance systems, but newer MANPADS include improvements that resist many countermeasures. Further, other ground-to-air weapons capable of firing explosive projectiles do not rely on guidance systems. For both large military and commercial aircraft, lethality is enhanced if the weapons can use an aircraft's fuel system against itself. The weapon's small impact area and warhead energy can be magnified into catastrophic airframe failure if a weapon can induce a fuel-tank explosion.

Accidental fuel-tank explosions in the civil transport fleet serve as examples. In 1996, TWA 800 broke apart in flight when its center fuel tank exploded. In 2001, a Thai Air B–737 was destroyed when its center fuel tank exploded while the aircraft was parked at a passenger boarding gate (see Figures 1 and 2 on page 17).

Military aircraft use fuel-tank inerting to protect against secondary explosion of fuel tanks struck by weapons. The cost of directly adopting the military technology to civil transports has been studied in the past and deemed too high. A subcommittee of the Aviation Rules Advisory Committee (ARAC), convened after TWA 800 to consider methods of fuel-tank protection, concluded that fuel-tank inerting was far too costly. Its conclusion was based on cost projections of the military inerting system used on the C–17 Transport.[3] In the meantime, the Technical Center of the Federal Aviation Administration (FAA) found that far less inerting is required to protect against accidental, low-energy ignition during flight and is less costly than that required for protection against military weaponry.[4] The FAA now intends to require fuel-tank inerting or its equivalent as protection against accidental fuel-tank explosion.

An over-arching goal of the Fuel Tank Explosion Protection (FTEP) project is to provide the means for affordable, effective fuel-tank protection to the commercial transport community. An objective is to limit aircraft explosion damage to enable flight to a safe landing using other technologies, such as Damage Adaptive Control Systems (DACS). Adoption of military-type inerting may mean protecting all a civil aircraft's tanks, not just the tank at greatest risk of accidental explosion, and may mean driving out more oxygen in each tank for greater protection against intentional ignition. These factors can raise the size and cost of a protection system by several hundred percent. FTEP objectives are keyed to increasing efficiency to reduce the size, weight, and cost of inerting against the high-energy military threats now presented by terrorism. The objectives are also keyed to providing new civil-design guidelines that address the in-flight fire-protection requirements of civil aircraft fuel systems against potential terrorist weaponry.

The FTEP research is joining the knowledge and experience of the NASA Glenn Research Center (GRC), Cleveland, Ohio, and the 46th Test Wing Aerospace Survivability and Safety Flight (ASSF) program at Wright-Patterson Air Force Base (AFB), Fairborn, Ohio. NASA GRC will use its expertise in fuel-combustion physics, sensors for harsh environments, and systems controls. The 46th Test Wing ASSF will draw on its expertise in military inerting technology, fuel-tank explosion dynamics, fuel-tank strength dynamics, testing of large structures under fire and aero loads, and testing of "iron bird" simulated fuel tanks.

The 46th Test Wing will perform studies and testing to

- achieve a better understanding of the requirements of civil aircraft fuel-system protection,
- develop design-guideline concepts for improved protection,
- develop methods to apply sub-scale testing to full-scale design, and
- generate inerting design concepts and guidelines.

NASA GRC will focus on developing technology to monitor tank flammability, to more efficiently inert multiple tanks, and to perform health monitoring of the fuel-tank protection system. It will perform studies and laboratory testing to

- develop rugged in-tank sensors to monitor conditions important to tank ullage flammability;
- develop an analytic model of fuel-tank flammability designed to take inputs from the in-tank sensors;
- create algorithms to control multiple flows of inerting gas to multiple tanks and using flammability feed-back to minimize

weight, size, and engine-bleed air penalty;

- Develop in-tank health monitoring by comparing flammability change with inerting-agent flow; and

- Perform a sub-scale laboratory demonstration of improved inerting performance by inerting-agent flow control via fuel-tank flammability feedback.

NASA GRC and the 46th Test Wing ASSF plan to assemble a future follow-on plan. It will identify the future testing and analysis procedures required to mature the fuel-protection design guidelines for commercial aircraft to the point of systems validation in a relevant environment. Some proposed testing, especially large-scale or full-scale, is expected to be coordinated through the Large Aircraft Survivability Initiative (LASI). ■

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3. FAA Aviation Rulemaking Advisory Committee: http://www.faa.gov/avr/arm/arac/wg_exe_FuelTankHarmonization.cfm?show=complete
4. "Safer Fuel Tanks," Air & Space/Smithsonian, June/July 2004

Mr. Robert C. McKnight received his MS degree in Industrial Engineering from Cleveland State University and his BS degree in Mechanical Engineering from the University of Akron. He served with the US Air Force for 25 years as a tactical airlift pilot. At the NASA GRC, he performed as a research pilot for 15 years in micro-gravity, in-flight icing, and remote-sensing flight programs. For the last seven years, Mr. McKnight has been project manager of several NASA research teams working to improve aircraft propulsion and fire and explosion safety. Currently, he manages the Accident Mitigation and the Fuel Tank Explosion Protection projects under NASA's Aviation Safety and Security Program. He may be reached at robert.c.mcknight @nasa.gov

Mr. Martin L. Lentz is the Technology Branch Chief for the ASSF program of the Munitions Test Division of the 46th Test Wing. He serves as the Co-Chairman of the Joint Aircraft Survivability Program (JASP) Survivability Assessment Subgroup and, since 1975, as a working member of the Joint Technical Coordinating Group on Munitions Effectiveness (JTCG/ME). He is currently Contracting Officer's Representative (COR) for the Survivability/Vulnerability Information Analysis Center (SURVIAC). Mr. Lentz received a BS in Industrial Engineering from Louisiana Tech University and a MS in Computer Science from Wright State University. Mr. Lentz has over 30 years of experience in survivability and vulnerability aircraft analysis, model development, and test verification of modeling and is recognized as the Air Force lead in modeling onboard fires and fuel-tank ullage explosions. He may be reached at 937.255.6302, Ext. 241.

Figure 1. Thai Air accidental explosion of center-wing tank, March 2001, Don Muong International Airport, Bangkok, Thailand

Figure 2. Remains of the left wing, engine, and fuselage—Thai Air accidental explosion of center-wing tank, March 2001, Don Muong International Airport, Bangkok, Thailand

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of the Aviation Safety and Security Program (AvSSP), an enhanced simulation for the B–757 that enables characterization of abnormal flight conditions, including loss of control, which will be essential to the safety-of-flight and recoverability assessments.

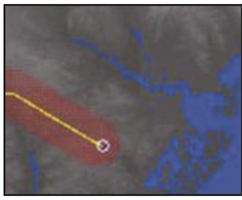
Test results from this effort will support C–5, KC–10, E–4, E–10A, B–747, B–757, B–767, MD–11, A300, A310, and A330 operational risk assessments and vulnerability analyses, which will then lead to improved safety-of-flight. Evidence of large-engine design strengths and deficiencies that are identified during this effort will be used to feed the design and requirements process.

In summary, planned LASI testing will help validate vulnerability assessments used to evaluate the operational risk of large aircraft within MANPADS threat environments. Aircraft MANPADS vulnerability tests and modeling and simulation results will together support national investment decisions concerning the scope of IRCM applications for transport aircraft. ■

Mr. Gregory Czarnecki received his BS degree in Civil Engineering and his MS in Materials Engineering from the University of Dayton, Ohio. He is a civilian with the 46th Test Wing's Aerospace Survivability Flight at Wright-Patterson AFB and is Lead Engineer within Large Aircraft Vulnerability to MANPADS and Aim-Point Biasing IRCM programs. Mr. Czarnecki serves as a subject matter expert for the Joint Low Altitude Aircraft Survivability program and is Structures Committee Chairman for the Joint Aircraft Survivability Program Office, working to reduce aircraft vulnerabilities associated with hydrodynamic ram and shoulder-launched missiles. He may be reached by e-mail at gregory.czarnecki@wpafb.af.mil.

Mr. Robert Yelverton received a BS degree in Geophysics from the University of New Orleans. Mr. Yelverton is a Principal Engineer at SENTEL Corporation and Deputy Program Manager for Live Fire Test and Evaluation (LFT&E) and Survivability programs at the 46th Test Wing's Munitions Test Directorate at Eglin AFB, Florida. Mr. Yelverton co-chairs the Large Aircraft Survivability Initiative (LASI) and is a research associate of the North Atlantic Treaty Organization (NATO) Sensors and Electronics Technology Panel. He may be reached at robert.yelverton@eglin.af.mil.

Mr. Carter (Ben) Brook's biography can be found on page 7.



MANPADS

The Military and Civilian Relationship

by Mr. Ray Schillinger

Almost 15 years ago, the Commercial Aircraft Hardening Program (CAHP) of the Transportation Security Administration (TSA), [formerly the Federal Aviation Administration (FAA)], participated in a series of Man-Portable Air Defense Systems (MANPADS) warhead tests against a commercial airframe. From the perspective of commercial aircraft survivability research, this was new ground, because the program had previously studied only the effects of internal blasts caused by improvised explosive devices. MANPADS were then not a primary concern, in contrast to recent high-profile events and current concerns. In the early nineties, "MANPADS" and its impact on world events was solely associated with the Russian–Afghani Conflict.

The CAHP has a strong background in internal blasts; however, it had no background in the MANPADS threat or other threats emanating from outside an aircraft. When this new study began, the FAA CAHP had the benefit of close cooperation with Department of Defense (DoD) technical leaders in aircraft survivability. The first example of participation was a static detonation in 1993 of a MANPADS against a retired commercial aircraft mothballed at Davis-Monthan Air Force Base, Tucson, Arizona. The CAHP provided high-speed photography, which can still be viewed today on the symposium circuit.

The list of credible players in aircraft survivability is small, and, as a result, it is inherently easy to identify activities with core expertise in aircraft survivability, weapons characterization, or both. The difficulty arises (because of timing, funding, requirements, *etc.*) in maximizing program resources by joining other organizations that are engaged in complementary efforts.

From the standpoint of civilian aviation, the military community is conducting the lion's share of work. Two of the CAHP's best partnerships are with the Joint Aircraft Survivability Program (JASP), along with its key members, and the Defense Intelligence Agency/Missile and Space Intelligence Center (DIA/MSIC). In the world of MANPADS, all queries begin with these two organizations.

With the support of DIA/MSIC, the CAHP conducted its first active test in 1994 to study MANPAD seeker performance in a commercial airport environment. Subsequent efforts have included key partnerships with the Air Force Research Laboratory (AFRL) and the Naval Research Laboratory (NRL), in efforts ranging from weapons effects to event forensics. In addition to playing the role of active research partner, the CAHP has engaged in one-of-a-kind efforts not traditionally studied by other organizations, such as component screening and area security.

Component screening

The wide array of airport screening techniques is familiar to all travelers. Screeners at airport checkpoints routinely look for contraband in the form of weapons or questionable material that could present a potential threat to the traveling public. The TSA administers the Threat Image Projection (TIP) program that is used today in airports across the country to train and monitor airport screeners. A TIP-ready X-Ray machine projects captured images of threats onto regular baggage, thereby allowing a screener's proficiency to be assessed. This in turn provides the ability to track screener training, screener assessment reports, and screener performance history. It also routinely exposes screeners to threat images to enable them to become more adept at recognizing guns, knives, Improvised Explosive Devices (IEDs), and other threat artifacts.

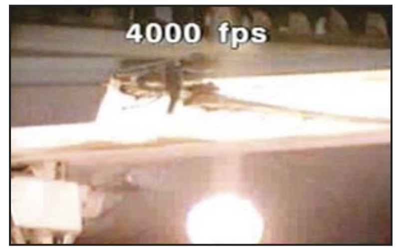


Figure 1. MANPADS warhead detonation

Figure 2. X-ray image of a pistol under screening conditions

A program was initiated to determine, in varying baggage configurations, what MANPADS consumables would look like under screening conditions. The rationale for this effort entailed a terrorist group transporting MANPADS components in luggage.

A test was conducted at the TSA's Transportation Security Laboratory (TSL). A major benefit of using this venue is the range of resources it offers, particularly in the field of explosives and weapons-detection

technology. The problem was not the availability of screening equipment for a dedicated test; the challenge was choosing from a vast array of machines that are either currently deployed or will be deployed in the next generation.

Three representative screening machines, which are typically found in airports worldwide, were used, providing both X-ray and computed tomography. The effort produced more than 100 images of baggage (in varying aspects) and baggage content, using different screening techniques.

Area security

In the summer of 1999, a joint CAHP/MSIC seeker study was conducted at the FAA Technical Center, which is co-located with the Atlantic City International Airport. During this activity, MSIC presented an informal discussion to the CAHP on Flight Path Threat Analysis Simulation (FPTAS). FPTAS originated at the US Transportation Command and the US Air Force Mobility Command as a tool to help planners identify and secure areas in which MANPADS could pose a threat to inbound or outbound traffic.

Before the appearance of easy-to-use modeling packages, the warfighter in the field typically did all flight-path threat plots by hand. Packages for commercial airport assessment were nonexistent. The CAHP, in coordination with MSIC, first began using FPTAS to determine if it was compatible with basic civilian application. From the standpoint of commercial aviation, FPTAS was first used in conjunction with a subsequent seeker acquisition study. Though seeker-to-target studies can never be replaced, FPTAS can provide both a good baseline assessment and an excellent planning document for field personnel in law enforcement and on threat-assessment teams. An initial survey can be conducted on the computer and later relayed to on-site activities for refinement.

Using National Geospatial-Intelligence Agency (NGA) Digital Terrain Elevation Data (DTED), which takes into consideration area and terrain

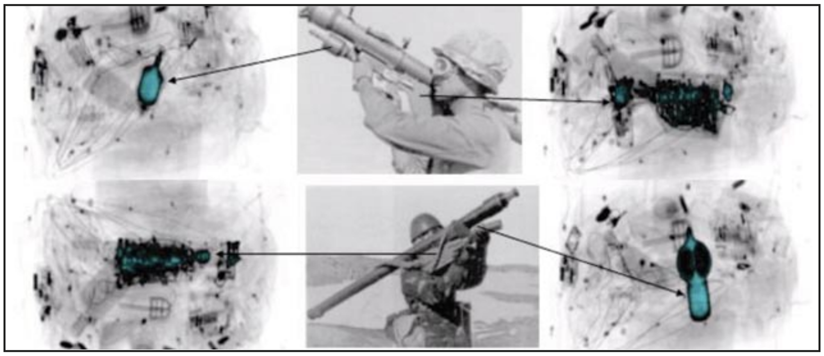


Figure 3. MANPADS components under screening conditions

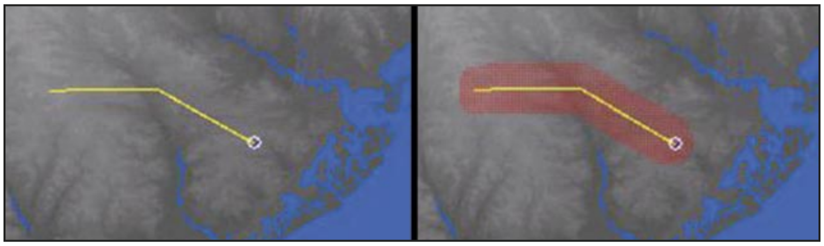


Figure 4. DTED mapping and flight-path integration

features, a user inputs a flight plot comprising heading, altitude, air speed, and other flight parameters (*i.e.*, Air Traffic Control data).

After identifying a specific MANPADS, FPTAS will calculate a threat envelope, taking into account a weapon's performance, terrain features, and aircraft parameters. Using readily available government or Commercial Off-The-Shelf Software (COTS), the plot can then be exported into several mapping and imagery formats.

Other features permit a user to quantify seeker performance, weapons kinematics, threat-exposure time, the level of threat within an envelope, and an entire array of other features that are beneficial to both operational planners and flight crews. With MSIC as FPTAS's configuration manager, the CAHP has benefited from using a tool proven by the military and also furthered the tool's development for commercial aviation operations.

Conclusions

The MANPADS threat for military and commercial aviation remains a complex issue. As specific threats are understood and addressed, new ones will appear. Therefore the efficient use of limited resources requires a collaborative military and civilian relationship. Lacking the resources to conduct an in-house investigation of more than 25 different MANPADS and their potential effects on commercial transport aircraft, the CAHP will continue with the following approach:

- Know what the military is doing, and tailor it to civilian purposes.
- Study all MANPADS, but concentrate the CAHP's efforts on the most likely threat(s).
- Maintain a thorough knowledge of aircraft survivability issues.
- Maintain an up-to-date intelligence assessment, and adjust accordingly.
- Maintain a liaison with operational activities.
- Maintain a liaison with research partners.
- Identify topics related to MANPADS that have not yet been studied.

Mr. Ray Schillinger is a graduate of Embry Riddle Aeronautical University and an Aerospace Engineer with the Department of Homeland Security Transportation Security Laboratory, Commercial Aircraft

Developing a Fuel-Tank Inerting System

for Commercial Transport Airplanes

■ *by Mr. William M. Cavage*

Significant emphasis has been placed on preventing fuel-tank explosions since the TWA Flight 800 accident in July 1996. The cause of this air disaster was later identified by the National Transportation Safety Board as an in-flight breakup of the Boeing 747–100 as a result of an overpressurization in the center-wing fuel tank caused by some unknown, internal ignition source that created an explosion of the flammable fuel vapors in the ullage. To protect against future accidents of this nature, the Federal Aviation Administration (FAA) has issued numerous Airworthiness Directives (ADs), enacted a comprehensive regulation to correct potential ignition sources in fuel tanks, and conducted research into methods that could eliminate or significantly reduce the exposure of commercial transport airplanes to flammable fuel-tank vapors. However, developing an effective, practical way to limit flammability in commercial transport fuel tanks had eluded the FAA for years.

Center Wing Fuel Tanks (CWT) and body-style fuel tanks are the fuel tanks contained partially or fully within the fuselage contour and are generally not cooled by ambient airflow, as is the case of wing tanks. Air-cycle machines, which generate air conditioning for the aircraft and reject heat, tend to be located immediately beneath most commercial transport CWTs. Also, the majority of commercial transport aircraft tend to operate with the CWTs empty, with just a small, unusable amount of fuel in the bottom of the tanks. It is because of this that these tanks have been identified as being potentially more flammable and statistically more susceptible to fuel-tank explosions.[1]

On two occasions, the FAA tasked the Aviation Rulemaking Advisory Committee (ARAC) to analyze potential regulations that would eliminate or significantly reduce flammable vapors in transport airplane fuel tanks. The ARAC committee is a government-sanctioned, aviation-industry committee that recommends regulatory language to government regulators that is amenable to the aviation industry. The first Working Group, the 1998 Fuel-Tank Harmonization Working Group, determined that traditional unheated aluminum wing tanks had an acceptable service history. Based on that determination, they recommended language that would limit the fleet average flammability exposure of new transport airplane fuel tanks. However, they did not recommend a requirement to reduce the flammability exposure of existing or new-production transport airplane fuel tanks. Instead, they recommended the FAA perform further studies of fuel-tank inerting and cooling of heated CWTs, and they recommended the FAA propose

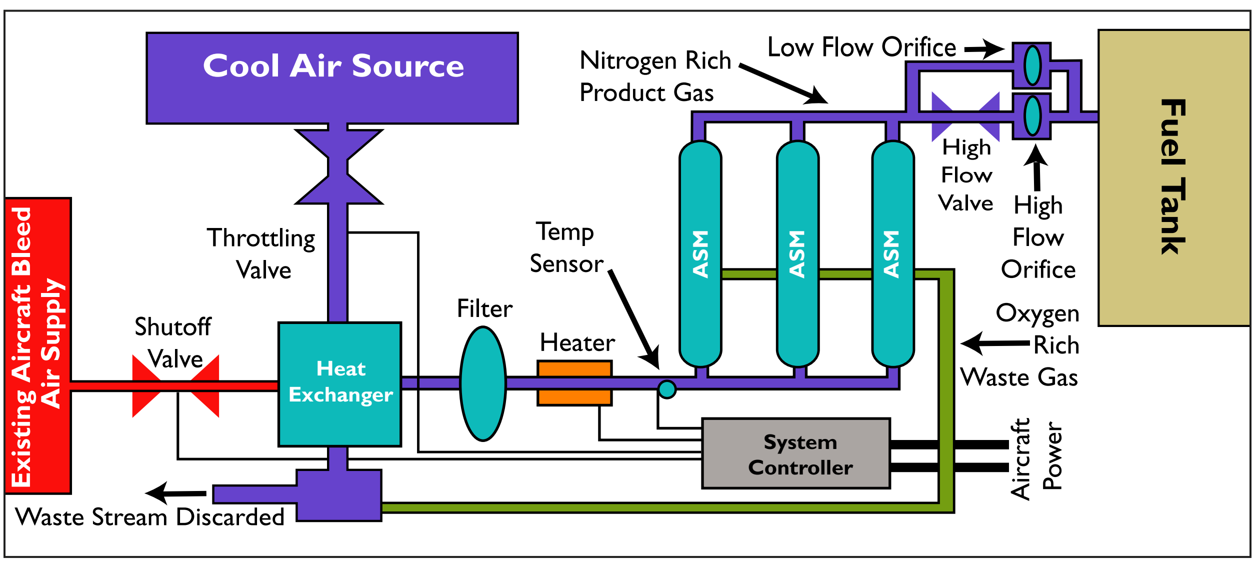


Figure 1. FAA simplified inerting system

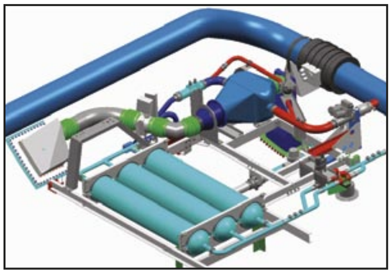


Figure 2. Three-dimensional rendering of the FAA inerting system

additional rule making if a practical method of reducing the flammability of existing designs was developed.

The second Working Group, the 2000 Fuel-Tank Inerting Harmonization Working Group, was tasked to study only fuel-tank inerting methods. This Working Group failed to generate a recommendation for rule making because of disagreements between some members of the Working Group and the FAA on both the cost of fuel-tank inerting and the effectiveness of the existing requirements in preventing future fuel-tank explosions.

Criticisms of existing fuel-tank protection technologies were not without merit. Some military platforms had traditionally relied on stored gas during combat to inert fuel tanks to protect against ballistic damage and secondary fragment ignition of flammable ullage vapors. For inerting to be effective in commercial airplanes, CWTs would need to be inert during much of normal operational time. This makes stored- gas inerting less practical for commercial aircraft, as the requirement for continuous servicing of stored gas systems at aircraft gates would result in extensive infrastructure improvements and the need of additional ground-servicing personnel.

Reticulated foam was a well-established and effective technology that employs nearly hollow foam blocks designed to fit in a fuel tank. The foam prevents propagation of a reaction caused by an ignition source in the ullage, thus eliminating the possibility of a deflagration/explosion. However, the operational penalty of foam includes a reduction in fuel-tank capacity and the added weight of wet foam, which somewhat limits the aircraft's range. Any fuel-tank maintenance is further complicated by the need to remove and store the foam. Also, disposal of the foam at the end of its useful life can be expensive, as time exposure to jet fuel will render it hazardous material.

The shortcomings of the above-mentioned inerting methods caused rule-making advisors to refocus efforts on Onboard Inert Gas Generation Systems (OBIGGS), which were generally believed by the aviation industry to be potentially more complex and costly, regardless of the trade studies that said differently. Virtually all military platforms relying on OBIGGS at the start of the rule-making Harmonization Working Groups in 1998 used pressure-swing absorption to generate nitrogen. This requires high-pressure air, not readily available on commercial transport airplanes, and was generally considered to be a complex and unreliable technology to apply. Some military aircraft programs using OBIGGS inerting have experienced difficulty meeting reliability and functionality requirements, including the V–22 program, which the author worked on in 1997.

Air separation by materials had been used in various niche applications for years, but in the 1980s so called Hollow-Fiber Membrane (HFM) air separation began to be applied for the purpose of separating air into its constituents. HFMs are hair-sized polymeric fibers that are woven like thread and grouped in a bundle known as an Air-Separation Module (ASM). When supplied with pressurized air, these modules will ventilate a waste stream of gas from a permeate port that is rich in oxygen, carbon dioxide, and water vapor.[2] This allows the product gas passing through the ASM to be rich in nitrogen and is referred to as Nitrogen-Enriched Air (NEA) to distinguish it from pure nitrogen. As back pressure is increased on the ASM product port, less NEA is generated, but at a lower oxygen concentration (more pure nitrogen). This behavior allows a single ASM to easily generate a wide range of flows and purities to optimize the effectiveness of a ullage-inerting process.

In the 1980s, an ASM OBIGGS study performed by the US Department of Defense (DoD) highlighted the favorable life-cycle costs of an on-demand inert gas- generation system as opposed to a stored inerting-agent system and explosive suppressant foam. This study concluded that an inerting system using state-of-the-art ASMs with HFM technology permitted a relative performance increase of a factor of ten over previous ASM technology systems.[3] It thus appeared that fuel-tank inerting in commercial transport airplanes could potentially be cost effective if

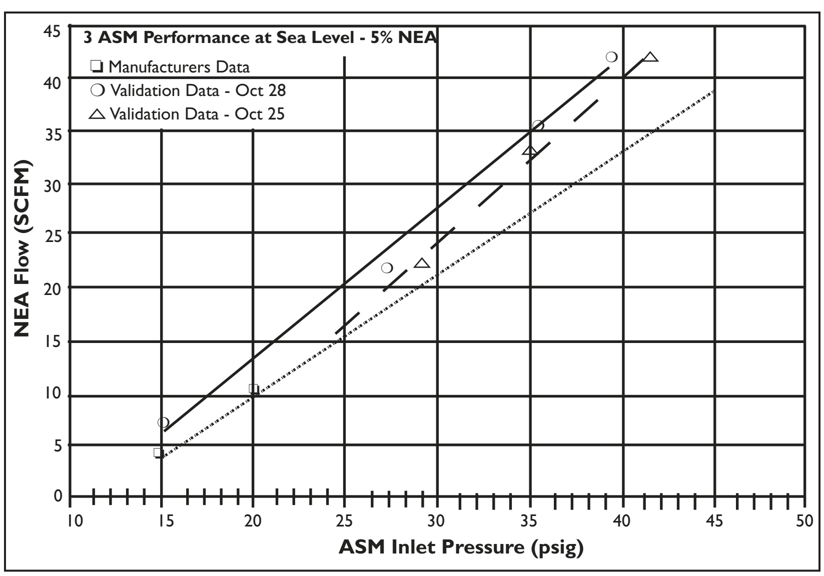


Figure 3. System performance validation data

ASMs, based on HFM technology, could be integrated into a system in an efficient manner.

It was the FAA Chief Scientist and Technical Advisor for Fuel Systems Design, Ivor Thomas, who first suggested the dual-flow concept for inerting a commercial transport CWT using ASMs. Although viewed by many with skepticism at first, it became apparent that this idea had some merit after Thomas created a basic model of how ASMs generate NEA at low supply pressures and developed a simple, effective system methodology.

Thomas' proposed system took advantage of recent FAA experiments that suggested the ullage oxygen concentrations below 12 percent by volume would protect a nearly empty fuel tank from an explosion/overpressure given a wide range of flammabilities and ignition sources.[4] Traditionally, the requirement for military aircraft has been more stringent because of the need to protect against ballistic threats. The system also took advantage of the unique characteristics of HFM ASMs and operated in a dual-flow methodology. This allowed the inerting system to create a very low oxygen concentration in the CWT ullage (one to three percent) using a low-flow mode during ground taxi, take off, and cruise. During descent, the system is switched to a high-flow mode, which limits (but does not eliminate) the amount of air entering the tank. This should allow for a resulting oxygen concentration in the CWT ullage of less than 12 percent if the system is sized correctly and gives a radical reduction in system size and resource requirements over a system designed to prevent air from entering the fuel- tank ullage completely.

System development

The Fire Safety Branch of the FAA, working with Ivor Thomas and several aviation-oriented companies, developed a prototype OBIGGS, using ASMs with dual-flow methodology, to inert a fuel tank throughout a commercial airplane flight cycle. The FAA system was designed to inert the CWT of a Boeing 747 classic type (-100, -200, or SP). It consists of a single, unregulated flow path that is plumbed to the manifold of three ASMs. The flow path has a heat exchanger, which controls the ASM air- supply temperature to 180°F ± 10°F, and a filter to remove particulate and moisture from the supply air. After the ASMs, a shut-off valve and two needle valves allow the system to operate in both low- and high-flow modes. The NEA is then plumbed to the fuel tank in an appropriate manner. Figure 1 (see page 20) shows a block diagram of the primary components of the inerting system.

The system was designed to meet the aviation industry standard RTCA DO–160 in a computer-aided design environment, although FAA certification of the system was never attempted. The system was constructed of aircraft-grade parts and built on a simple, aluminum-frame pallet to allow simplicity of construction and installation. Figure 2 (see page 21) shows a three-dimensional rendering of the system in the empty part of a Boeing 747 pack bay with the existing 8-in-diameter bleed air duct (in blue) as a spatial reference.

System validation test

The FAA inerting system was initially tested on a 747SP ground-test article used to study fuel-tank inerting and flammability. The FAA OBIGGS provided a somewhat wide range of performance, given similar input parameters and operating conditions. Figure 3 (see page 21) shows that the system provided 10–20 percent greater performance on the 747SP ground-test article at sea level than predicted by the manufacturer's data. This was not unexpected, because the manufacturer's data was based on a single ASM static test. Each ASM will perform slightly different because of subtle dissimilarities in manufacture and assembly. The difference in performance on different days during validation measurements was attributed to different ambient temperatures and system-environment temperatures. Although a somewhat constant ASM input temperature and pressure was maintained over an extended period of time, it appeared an isothermal environment was needed to get completely stable performance data.

To validate the inerting system concept and examine its dynamic performance, the FAA OBIGGS was tested, in conjunction with Airbus, on an A320 flight-test aircraft operated for the purposes of research and development. The system was mounted in the cargo bay and plumbed to inert the aircraft's CWT. It was operated using only one ASM to size the system to better match the test aircraft. The difficulty in obtaining stable ASM performance data is evident when examining data acquired during a typical test flight (see Figure 4 this page), which involved a short taxi, take off, and ascent to 39,000 feet. After cruise, the aircraft then

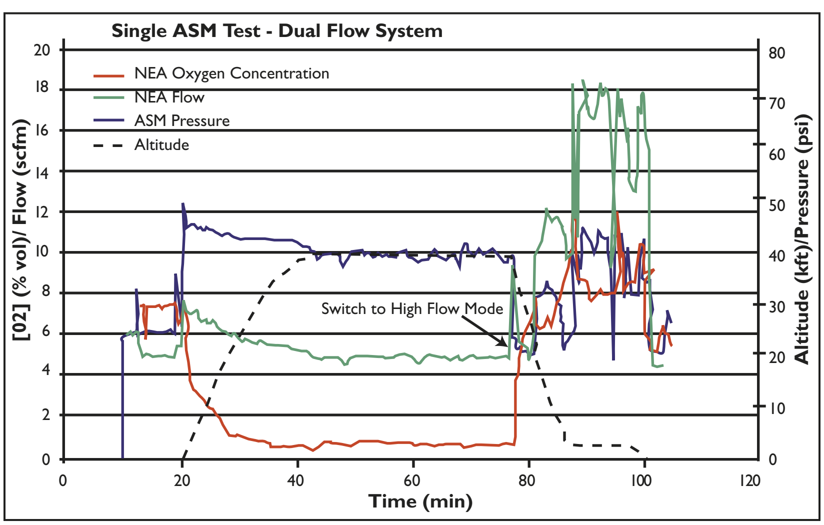


Figure 4. Dynamic ASM performance data from the A320 flight-test article

descended very rapidly to 3,000 feet to simulate the limit of safe aircraft-descent operations if it were to land at an airport unencumbered by air-traffic control.

The flight-test data in Figure 4 (see page 22) illustrates the relationship between ASM pressure, altitude, and NEA flow. In general, increasing ASM inlet pressure will increase NEA flow and purity (decreasing oxygen concentration) simultaneously, given a fixed orifice setting. This is because an increase in flow across a fixed orifice will result in a greater pressure drop, and an increase in pressure drop across the system-flow orifice (with all other things being the same) will result in a decrease in oxygen concentration. As aircraft altitude increased, the ASM tended to generate less flow (in terms of sea-level conditions) at a lower oxygen concentration (more pure nitrogen), because of the changing permeability characteristics of the ASM fiber. During the descent, the high-flow mode was selected, giving an instantaneous increase in flow and decrease in purity to help stave off airflow into the fuel-tank ullage through the vent system because of changing air pressure. As the aircraft descends with the system in the high-flow mode, NEA flow increases as purity decreases (greater oxygen concentration).

The effectiveness of the inerting system in terms of lowering the oxygen concentration of the ullage of the CWT was measured to gauge the size of the system for a given commercial transport fuel tank. Figure 5 (see above) gives the measured fuel-tank average ullage oxygen concentration during the same test compared to a simple ullage inerting model that calculates the ullage oxygen concentration, given a flight profile and measured system performance. As designed, the system drastically lowered the oxygen concentration of the ullage very quickly during taxi, take off, climb, and the first part of the cruise. The high-flow mode was then used during descent to counter the flow of air entering the fuel-tank vent system. This kept the ullage oxygen concentration below 12 percent the entire flight, even given the aggressive nature of the descent profile, and gave a resulting oxygen concentration of 10 percent when the aircraft arrived at the gate after landing and ground taxi. This performance provides sufficient margin for a lengthy turn around and potential fueling of the tank, maintaining a CWT ullage oxygen concentration of less than 12 percent by the start of the next flight cycle. Provided this flight profile illustrates the limit of necessary inerting-system performance, the system would be able to maintain and inert ullage in this CWT 100 percent of the time with the exception of maintenance actions and potential emergency descents outside the limits of the descent employed for the testing.

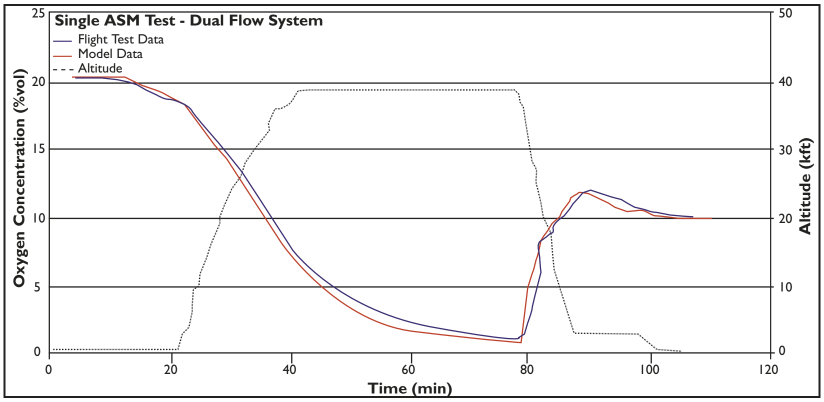


Figure 5. Ullage oxygen concentration data from the A320 flight-test article

In summary, OBIGGS has been found to be a cost-effective way of inerting aircraft fuel tanks, provided care is taken to create a reliable, effective system. Through research, testing, and analysis, the FAA developed a prototype fuel-tank inerting system using ASMs based on HFM technology that is designed to inert the CWT of a Boeing 747 (classic type) during normal flight and ground operations. The results of the tests indicated it could be difficult to duplicate static system performance on an aircraft test bed because of the difficulty in obtaining stable conditions on an aircraft operating in a normal manner. The flight-test results indicated that the system concept was valid, and it reduced the oxygen concentration of the ullage sufficiently to provide ample protection to the fuel tank during the entire flight cycle. ■

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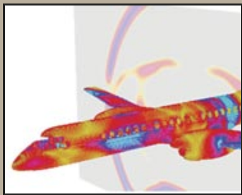

Assessment of Electromagnetic Effects (EME) on Commercial Aircraft

■ *Mr. John Beggs and Mr. David Smith*

Since the late 1950s, there have been concerns of Portable Electronic Devices (PEDs) potentially affecting aircraft electrical and electronic systems. At that time, an industry committee, Radio Technical Commission for Aeronautics (RTCA) SC–88, was established by RTCA to investigate interference to aircraft electronic equipment from PEDs. Since that time, three other RTCA committees have continued to address potential aircraft Electromagnetic Effects (EME) caused by new and emerging consumer technologies, culminating in the current SC–202 committee. The potential hazards of unauthorized EME to aircraft operation can range from simple nuisance events, such as triggering smoke alarms or emergency lighting, to more undesirable events, such as communication and navigation radio interference or interference with emerging aircraft wireless Internet, picocell, and security systems. It could even result in potentially catastrophic events, such as interference with electronic navigational aids and systems, which are of particular importance on final approach or in severe weather environments.

Currently, the Federal Aviation Administration (FAA) certifies large-scale commercial aircraft for immunity to EME and exposure to High-Intensity Radiated Fields (HIRF), as outlined in RTCA's DO–160D test standards. However, the DO–160D standard was designed to provide immunity against unintentional Radio Frequency (RF) emissions and does not address intentional, in-band, on-channel RF emissions. Furthermore, a gap in US spectrum policy relies on voluntary compliance to not operate unauthorized transmitters in aviation frequency bands. Additionally, recent licensing by the Federal Communications Commission (FCC) of Ultra-Wideband (UWB) technologies (and other emerging RF technologies) may decrease operational aviation RF safety margins by increasing the overall noise floor in the electromagnetic spectrum.

During the past several years, NASA Langley Research Center (LaRC), in collaboration with the FAA, United Airlines, Delta Airlines, SkyWest Airlines, and Eagles Wings, Inc., has assessed Interference Path Loss (IPL) on several different aircraft types, including large-scale commercial transports and smaller regional aircraft. An IPL is the primary factor in assessing the operational risks of EME caused by unauthorized or hostile transmitters carried on a commercial aircraft. A large database currently exists of IPL measurements on these various aircraft from inside passenger compartments. However, a significant void in the database is an IPL from inside a cargo compartments and a cockpit. Also, the airline's desire to provide enhanced passenger connectivity through wireless networks and picocell phone networks serves to increase the difficulty in assessing the operational risks of EME.

Test planning has already begun within the Large Aircraft Survivability Initiative (LASI) program to assess EME aboard commercial aircraft. The planning efforts are concentrated in two primary areas: Electromagnetic (EM) environment characterization and retrofit countermeasures. By performing rigorous IPL measurements from the cockpit, passenger cabins, galleys, lavatories, crew compartments, and cargo compartments, the EM environment aboard a commercial aircraft will be completely characterized to identify coupling paths. These coupling and other test measurements will be used to design and support tests at Eglin Air Force Base (AFB), Valparaiso, Florida, of several simulated RF attack scenarios. These tests will be used to enhance operational risk assessments of the magnitude of the EME threat. Retrofit countermeasures, such as conductive paint coatings, transparent conductive window films, and absorptive passenger and cargo compartment loading, will also be investigated to enable RF surveillance and detection inside an aircraft and to reduce the likelihood of both front-door and back-door RF coupling, which would increase survivability against unanticipated EME.

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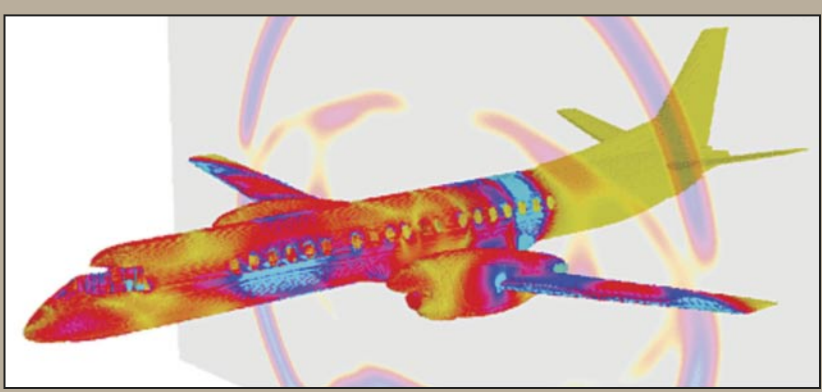

Figure 1. Notional EME interference contours

The SECAD Project: Vulnerability Reduction via Propulsion Control Logic

■ Mr. Charles Frankenberger and Dr. Alan Pisano

Next-generation fighter aircraft will be powered by a new generation of turbine engines that use the latest in digital-control technology that will enable significant advances in performance, operability, and health management. These new technologies will also enable the next level of increased survivability for both wartime and peacetime scenarios and thus provide an opportunity to reduce engine vulnerability and increase aircraft safety without reducing performance or adding weight. Propulsion is a critical system for any platform; it provides electrical and hydraulic power, ECS air and thrust. If the vulnerability of propulsion systems can be reduced, the probability of successfully completing a mission is increased. The Joint Aircraft Survivability Program Office (JASPO) sponsors the Survivable Engine Control Algorithm Development (SECAD) project, which takes advantage of these technologies and applies them in a new, extreme manner. Initial feasibility results have been significantly extended and validated, and these technologies are now ready for early transition and for leveraging to other platforms.

Survivable engine controls

Survivable engine controls monitor engine operation, detect damage to the engine that results in a shift in engine performance, and adjust the engine-control schedules to minimize performance loss. The key to this technology is the ability to rapidly detect and classify engine damage. Engine damage propagates extremely quickly. As an engine's performance changes following damage, the engine control reacts to the change and, in many cases, perpetuates the damage. This results in catastrophic damage to the engine and possibly the aircraft. SECAD monitors the engine's critical parameters (speeds, pressures, and temperatures) in real time to determine if damage has occurred. When damage does occur, SECAD algorithms simultaneously attempt to detect and classify the damage so that proper mitigating control changes can be made.

Initial feasibility results were presented in the Summer 2001 issue of "Aircraft Survivability." These results showed that the concept worked as a point solution for several important types of engine damage. What remained to be shown is how these concepts could be extended to cover the entire flight envelope in the presence of realistic and rapid transients, such as those that might be experienced in combat. The types of failures considered in the previous study included fan and compressor damage, combustor damage, and damage to the Variable Exhaust Nozzle (VEN). In addition to these, the following new failure modes are now part of SECAD: high-pressure turbine and damage (holes) to the Afterburner (A/B) case. This new "full-envelope, all-power level" SECAD has now been successfully tested on an F414–GE–400 turbofan engine.

Full-envelope SECAD design

The full-envelope SECAD design expands the capability of damage detection and mitigation algorithms from the narrow envelope of the previous effort to a realistic engine operating envelope. A realistic "full-operating envelope" was chosen to be [0, 35000] feet, [0.0, 1.2] Mn, [-30°, 60°] Tamb, and [50°, 132°] Power Lever Angle.

SECAD design phase

The design phase of SECAD is relatively complex and requires a detailed thermodynamic cycle model of the engine, which has been modified to incorporate the effects on engine damage. The current design of SECAD includes the following types of damage:

- Engines with fan and compressor damage
- Engines with a combustor leak,
- Engines with VEN damage
- Engines with high-pressure turbine (HPT) damage
- Engines with High-Payoff Target (HPT) damage

Damage models for each damage type were built using engine data from previous testing and from field events. Generating damaged-engine performance data is the first key component of the design. SECAD steady-state data was generated from the cycle model of the F414–GE–400, including extended flight-envelope and engine operating conditions. The data was parameterized in terms of altitude, inlet Mach number, inlet temperature deviation from standard day conditions, and Power Level Angle (PLA). PLA is the engine-throttle input and is correlated to the desired level of thrust that is to be produced. Then, for each power region, random levels of new engine variation and deterioration, together with the random points in the "full-operating envelope" were generated for approximately 6,000 cases (1,000 for each damage type and 1,000 for undamaged engine cases).

Using these data, an engine damage estimator, **R**, is constructed, based on the engine sensor values, signals available from the Full Authority Digital Engine Control (FADEC), and fault definitions. A mathematical "model" of each damage scenario was built using a linear com-

bination of sensed values from the database of simulated engines with each damage type. A block diagram of this process is shown in the upper half of Figure 1 (see below).

SECAD implementation phase

Once the damage estimator has been designed, the implementation phase is relatively easy. Two separate damage-estimation schemes have been developed. One scheme, using "absolute detection," looks for changes in the current state of the engine thermodynamically with the state of a nominal engine at the same operating conditions. The second is a "relative-detection" method that looks for shifts in engine thermodynamic conditions as they evolve over time.

To complement each other and to resolve conflicts, the absolute- and relative-detection schemes must be combined. Both absolute and relative detection estimators are executed in parallel and generate two independent damage estimates. The damage estimates are compared with the thresholds, T, and are checked for persistency, P, so that transient behavior does not cause false-damage flags. The relative scheme reacts to damage more quickly and tends to be more accurate than the absolute scheme; if it gives a damage flag, it takes precedence over the absolute scheme. The relative scheme can be tricked into silence by transients and gradual damage; if it detects no damage, the absolute scheme is polled for results. Next, a confidence is computed for the damage estimate. The confidence is based on whether the two schemes agree, how long it has been since a throttle transient, etc. Finally, the power level is range checked to make sure the engine is within acceptable operating conditions. This process is shown in the lower half of Figure 1.

Damage mitigation

Once damage is detected, the FADEC can send an engine indication to the pilot and steps can be taken to minimize the negative effects and/or to prevent engine failure. The objective mitigation action is to minimize these effects while maintaining the greatest amount of engine capacity, whether at maximum thrust or by simply keeping the engine operating to provide get-home capability. On FADEC engines, it is possible to alter some or all control schedules; *e.g.*, fan and compressor rotor speeds, variable-guide vane position, variable-exhaust nozzle position, A/B scheduling, combustor fuel flow, low-pressure turbine exit temperature, acceleration and deceleration schedules, and others. These modifications are not accessible to the pilot and thus truly represent a "reconfigurable" engine control.

SECAD engine tests

A six-week, extensive test was conducted on a F414–GE–400 engine during October and November 2003. The purpose of this test was to validate the SECAD algorithms with actual hardware.

Test setup at China Lake

Testing was conducted at the Naval Air Warfare Center, Weapons Survivability Laboratory (WSL), China Lake, California. Testing was conducted on the WSL C2 pad and was installed per standard F414 interface requirements (see Figure 2 on page 27).

Several data-collection and monitoring systems were used to perform various functions during the SECAD testing. A F414 FADEC Interface System was used to provide 1553 bus-control fuctions, providing required data to the FADEC, including throttle-input and record 1553 data. A Windows Acquisition Reduction and Processing (WARP) data-collection system was also used to collect and analyze engine data. This system monitored the 1553 bus and collected the additional engine temperature and pressure information required to run General Electric's engine performance codes. This system was also used to host the SECAD algorithms.

Extensive data was recorded to evaluate the ability of the SECAD damage-detection algorithms to correctly determine the type of damage to the engine and to continuously determine the level of engine-performance degradation caused by the damage. The graphical display, monitored in the control room, is shown as Figure 3 (see page 27).

Combustor damage test

For this test, the customer bleed pipe and valve was installed with a 2.0-in diameter orifice plate. This valve was snapped open to simulate a hole in the combustor.

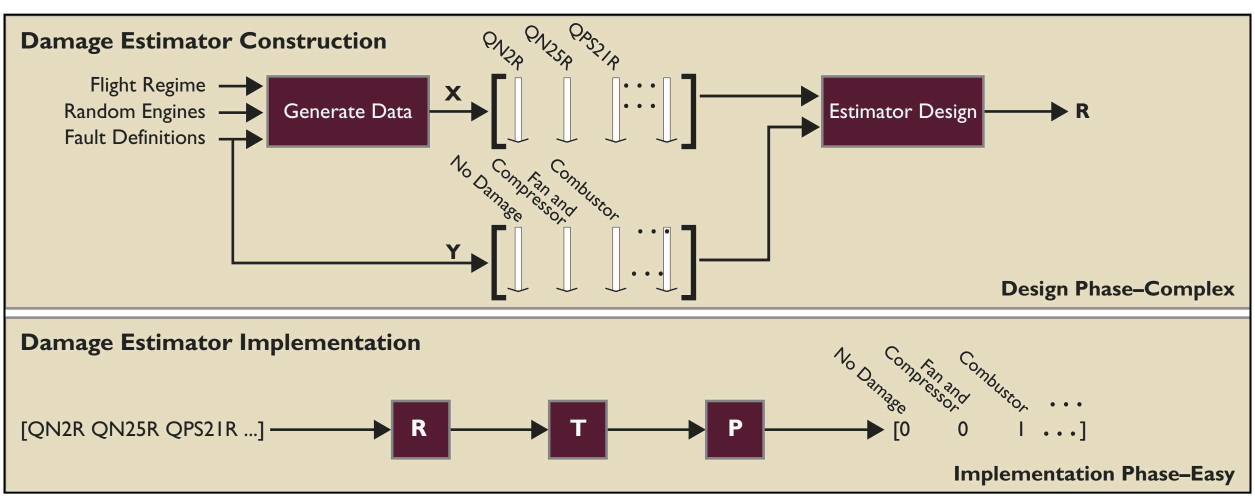

Figure 1. SECAD block diagram

Testing was repeated with orifice plate in sizes of 1.5 inch, 1.0 inch, and 0.8 inch diameter (see Figure 4 below).

Sea-level VEN loss-of-control test

For this test, the VEN was forced open to simulate the loss of the actuation system.

High-Velocity Airflow System (HIVAS) combustor damage test and HIVAS VEN loss of control

HIVAS is a system for introducing high-velocity air to the inlet of an engine. For this part of the test, inlet-air velocity was adjusted up to Mn 0.7, both steady state and transiently swept, from 0.2–0.7 Mach.

Figure 2. Engine test setup at China Lake

Fan and compressor damage

Fan and compressor damage was simulated by suddenly injecting a large quantity of hot air into the air stream ahead of the engine, while holding T2 at near-ambient conditions. Hot air was produced using an airflow rig (Huff and Puff). Huff and Puff, a trailer-mounted, TF30 turbofan engine, has a butterfly valve that can quickly re-direct the TF30 bypass air to the test article.

A/B case damage

For this testing, a large hole was made in the A/B case and liner. This hole was covered by a sacrificial plate on which was placed an explosive charge that could be formed to allow various-sized holes to be made into the plate when detonated. These charges were detonated during the test to simulate ballistic holes in the A/B section of the engine.

VEN ballistic damage

The final test involved a ballistic projectile shot at the VEN.

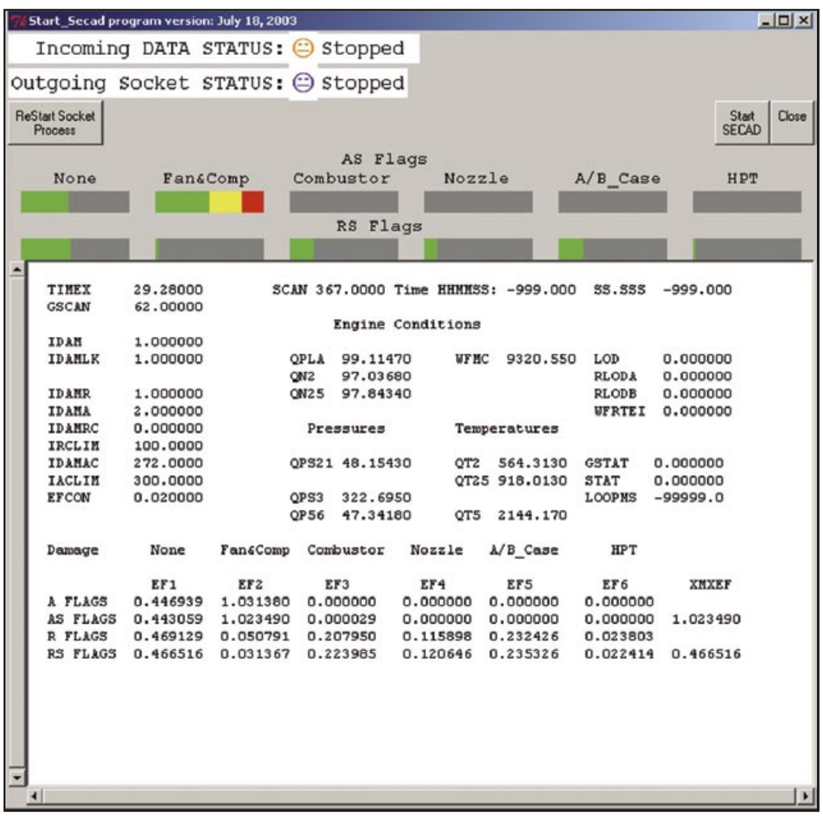

Figure 3. SECAD test-cell display interface

Figure 4. Combustor damage test setup

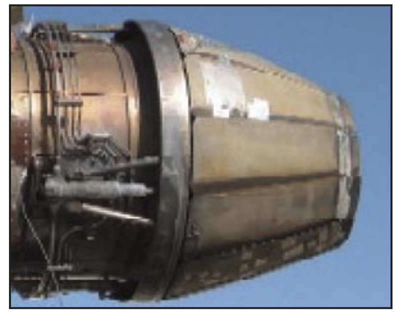

Figure 5. Variable Exhaust Nozzle (VEN) shown in closed position

Figure 6. HIVAS test setup

Figure 7. Fan and compressor damage test setup with "huff and puff"

Figure 8. Hole in A/B case after detonation

Engine test results

Engine test results are summarized in the following tables:

Test Case	Detected by SECAD?
SLS VEN Loss of Conrol	
IRP	YES
MAX	YES
70%	YES
HIVAS VEN Loss of Control	
IRP (m=0.4)	YES
IRP (m=0.4)	YES
MAX (m=0.4)	YES
70% (m=0.4)	YES

Table 1. SECAD detection—VEN loss of control

Test Case	Detected by SECAD?
SLS Combustor Damage	
0.8” Orifice	
IRP	YES
MAX	YES
70%	YES
1” Orifice	
IRP	YES
PLA=110	YES
70%	YES
1.5” Orifice	
70%	YES
HIVAS Combustor Damage	
1.5” Orifice	
IRP (m=0.4)	YES
PLA=124 (m=0.4)	YES
70% (m=0.4)	YES

Table 2. SECAD detection—combustor damage

Test Case	Detected by SECAD?
Fan & Compressor Damage	
PLA 115, 28-deg	YES
IRP 35-deg	YES
IRP 28-deg	YES
IRP 21-deg	YES
IRP 10-deg	YES
70% 35-deg	YES
70% 28-deg	YES
70% 21-deg	YES

Table 3. SECAD detection—fan and compressor damage

Test Case	Detected by SECAD?
AB Case Damage	
70%, 8” diam. (50in^2)	YES
IRP, 8” diam. (50in^2)	YES
IRP, 5.6” dia,. (25in^2)	YES
VEN Ballistic Damage	
VEN Shot	YES

Figure 9. High-speed photo of A/B case detonation

Table 4. SECAD Detection—A/B case damage and VEN ballistic damage

As shown in these tables, SECAD correctly detected the damage injected in *all test cases*.

After SECAD correctly detected the damage, mitigation was introduced to recover much lost engine thrust. For most damage types, SECAD is able to recover approximately 50 percent of thrust lost in the wake of the damage.

Specifically, each damage type introduced during the engine test resulted in the following:

Damage Type	Thrust Recovery
VEN Loss of Control	47.1%
Combustor Damage	52.1%
Fan and Compressor	16.4%
Damage AB Case Damage	27.6%
VEN Ballistic Damage	58.0%

These numbers were averaged over the test cases that were run. These numbers will vary depending on the condition of the engine before damage occurs. The engine used for testing at China Lake was a factory-development engine that was “retired” to China Lake after 1,500 factory test hours. The engine’s condition before the SECAD testing had already deteriorated to such an extent that it would have been removed from the field. In light of the engine’s condition, then, the thrust-recovery numbers obtained during the SECAD testing are especially significant.

Summary and future direction for SECAD

SECAD has now been developed into a “full-envelope, all power level” design and has been validated on a comprehensive engine test at China Lake and by extensive simulation. For the F414 application, most damage scenarios that SECAD will detect are not detected by the current FADEC logic. Thus, without SECAD, there is no pilot cueing of engine gas-path damage.

Figure 10. VEN damage after ballistic shot after detonation

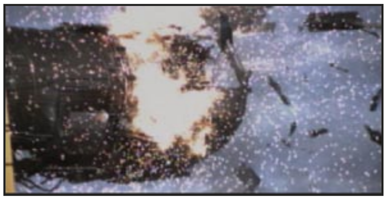

Figure 11. High-speed photo of VEN ballistic shot

Proper damage mitigation permits the pilot to take the right corrective action, based on his current situation. If damage occurs in a hostile area or immediately following a catapult launch, providing the most thrust available from the damaged engine could make the difference in surviving the event. During less stressing scenarios, after engine damage has been detected and mitigation invoked, the pilot could simply pull back power or shut down the damaged engine on a multi-engine aircraft. Anything that can be done to provide that extended capability will save lives.

Taking advantage of the ability to detect small-to-large levels of engine damage from ingestion or from mechanical or ballistic events provides a wide range of possibilities. Two uses that immediately come to mind are SECAD for turboshaft engines used in helicopter applications and SECAD for large turbofan engines used in commercial and transport aircraft. For helicopter application, detection and potential mitigation of damage could significantly improve flight safety and survivability. SECAD can provide key engine-health information to ease the pilot's decision-making process and provide added power required to get home. For commercial and transport application, identifying which engine is damaged is a serious issue that has lead to the loss of many aircraft over the years. SECAD can provide engine damage detection to alert a pilot and identify which engine is damaged, again providing critical information to a pilot during an engine-failure event.

For each system, SECAD can provide an added level of safety and survivability using existing engine sensors through an update to FADEC software. ■

Mr. Charles Frankenberger has worked in the propulsion field at the Naval Air Warfare Center Weapons Division (NAWCWD) for 18 years, eight years in missile propulsion and the past ten years pursuing engine-vulnerability issues and conducting Live Fire Testing on turbine engines. He is currently lead project engineer on the SECAD and Engine Damage Detection projects and chairs the JASPO Vulnerability Reduction Subgroup Propulsion Committee. He may be reached by e-mail at charles.frankenberge@.navy.mil.

Dr. Alan Pisano has worked for General Electric since 1968 where he was a member of GE's Advanced Course in Engineering program. Mr Pisano has received an MSEE and PhD and, since 1974, has worked in the controls-technology area, applying state-of-the-art controls to advanced turboshaft and turbofan engines at GE's Lynn, MA, facility. He is the prime technology contact in the controls Center of Excellence and coordinates the General Electric Aircraft Engines (GEAE) controls-technology programs based in Lynn. He may be reached by e-mail at alan.pisano@ae.ge.com.

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In a complementary effort, the 46th Test Wing at Eglin AFB has an agreement with the Transportation Security Administration to research previous RF testing on large commercial transport aircraft. The RR sources tested, their affects on avionics and flight-control systems, and the types of aircraft that have been tested will be identified. The results of this effort will be used to determine the data voids that exist for RF interference aboard large commercial aircraft and to recommend future testing to support LASI planning activities.

The avionics suite from the LASI test aircraft will eventually be integrated into the Systems and Airframe Failure Emulation Testing and Integration (SAFETI) laboratory at NASA LaRC to provide a closed-loop HIRF testing capability that can assess pilot's reactions to simulated EM interference events. The results of this testing can lead to new or improved operational procedures. These research and development efforts will be used to support national investment decisions in new FAA mandates for improved RF shielding and updates to the DO–160 standard. ■

Mr. John Beggs received his BS and PhD degrees in Electrical Engineering from The Pennsylvania State University and his MS degree in Electrical Engineering from Georgia Institute of Technology. He is a civilian staff member of NASA LaRC and a project manager for Aviation Security Electromagnetic Effects. He may be reached at John.H.Beggs@nasa.gov.

Mr. David Smith received his BS degree in Systems Science from the University of West Florida in 1988. He is currently a Weapons System Analyst with ORION International Technologies supporting the Technical, Engineering, and Acquisition Support contract and the 46th Test Wing's Munitions Test Division at Eglin Air Force Base. He may be reached at david.smith3@eglin.af.mil.

Evaluating of Counter Man-Portable Air Defense Systems (MANPADS) Tactics

■ *by Col. Miroslav Jencik, Mr. Bill Herman, and Mr. Gregory J. Czarnecki*

In September 2004, the Director, Operational Test and Evaluation, in cooperation with the Executive Steering Group, established the Joint Low Altitude Aircraft Survivability (JLAAS) Quick Reaction Test (QRT). The JLAAS QRT is a one-year, joint test directed to produce recommended Tactics, Techniques, and Procedures (TTP) to mitigate identified problems and reduce US casualty rates in the Iraqi theater of operations.

During JLAAS QRT nomination development, team members contacted numerous agencies to determine if arrival and departure TTP used in Iraqi operations by fixed-wing and rotary-wing aircraft had been tested, and if a validated process for evaluating and developing these TTP exists. After discussions with a number of organizations and agencies, including the US Central Command (USCENTCOM), the Air Mobility Command (AMC), the Air Force Special Operations Command (AFSOC), the US Army Aviation Center (USAAVNC), the Marine Aviation Weapons and Tactics Squadron-One (MAWTS-1), and others, the nomination development team concluded that existing arrival and departure TTP have not been evaluated for effectiveness for the aircraft types to be tested, and that no rapid, validated process exists for evaluating and developing arrival and departure TTP against MANPADS.

Scope

The JLAAS QRT investigates defensive measures that aircrews employ to increase survivability while executing arrivals and departures at airfields in hostile Man-Portable Air Defense Systems (MANPADS) environments. Specifically, the JLAAS QRT assesses selected arrival and departure TTP for one heavy fixed-wing aircraft and one rotary-wing aircraft. The JLAAS QRT Joint Warfighter Advisory Group (JWAG) played a major role in selecting the specific, current TTP and the aircraft type (C-130H and UH-60L) included in the field test. JLAAS focus is on assessing the effectiveness of pre-launch (pre-emptive) TTP and developing a rapid method of evaluating and developing TTP.

The Air Force Joint Test and Evaluation Group (AFJTEG) at Kirtland Air Force Base (AFB), Albuquerque, NM, uses a combination of techniques for data collection and analysis to meet JLAAS QRT program objectives. The first phase of the QRT was an investigative or data-gathering phase. This phase included a review of incident data, current TTP, previous MANPADS tests and studies, and test-asset requirements and availability. The second phase of the QRT used Modeling and Simulation (M&S) to assess selected TTP in a threat environment, develop test scenarios, and define scenarios and field-test conditions. The third phase consisted of a field-test event focused on collecting quantitative and qualitative data in realistic operations and threat environments. During the fourth and final phase, the AFJTEG will import field-test data into M&S to complete an assessment of TTP effectiveness for Balad Airfield, Iraq. After completing the analysis of Balad Airfield, the AFJTEG may extend its analysis to other airfields and test conditions to demonstrate that the JLAAS process is extensible to a broader range of applications.

The JLAAS modeling process began with a combination of the Joint Integrated Mission Model (JIMM) and the JMASS Threat Engagement & Assessment Model (JTEAM) to generate aircraft detection, missile acquisition, missile lock-on, and missile fly-out metrics. A gunner's and a missile's ability to engage was integrated over a large-threat lay down and used to rank the relative effectiveness of aircraft tactics. With initial modeling results in hand, a JLAAS field test for model validation was performed. Testing was conducted over a three-week period in May at the Marine Corps Air Station, Yuma, AZ. C-130 and UH-60 test assets flew an assortment of currently used arrival and departure tactics over a MANPADS threat lay down consisting of trained gunners armed with SA-16 Portable Air Defense Simulators (PADS). During each pass, metrics were recorded to quantify the gunner's ability to engage. Metrics included the amount of time the aircraft was in the launch envelope, time of detection, number of missiles launched at the aircraft, and projected missile hits. When trigger pulls occurred, the exact engagement scenario is fed into JTEAM for missile launch and completion of the fly out to determine good and bad shots. Once M&S is validated against field tests, the AFJTEG will perform a full M&S investigation of selected counter-MANPADS tactics. Metrics of effectiveness will then be integrated to achieve TTP ranking.

Products

A primary product of the JLAAS QRT is a quantified assessment and comparison of selected TTP identified by the first JWAG. The specific form of this test product is determined by the second and third JWAGs and during coopera-

tive efforts with AMC, USAAVNC, and USCENTCOM. TTP effectiveness will be disseminated to combatant commands, component commands, TTP developers, training commands, and other agencies through JLAAS QRT briefings, and the JWAGs and will be included in the final report.

The AFJTEG will also select and refine an engagement model that permits tactics developers to quickly perform timely, end-to-end TTP evaluations. The M&S process of TTP evaluation will be adaptable to various aircraft at different airfields within other areas of operation. The JLAAS TTP Evaluation Model (JTEM) will be a key product of the QRT, along with a "user's guide" that describes the JTEM and walks tactics developers through the TTP assessment process. This user's guide will identify modeling tools and a process that mission planners and operators can apply to conduct rapid, reliable assessment of current TTP and to explore the potential effectiveness of TTP options at different airfields.

In summary, the JLAAS QRT will assess metrics of TTP effectiveness that will be used to guide TTP selection. These solutions will have broad applicability throughout the joint community. ■

Colonel Miroslav Jencik is Air Force Joint Test and Evaluation Group test director, Headquarters Air Force Operational Test and Evaluation Center (AFOTEC), Kirtland Air Force Base (AFB), New Mexico. He is responsible for the conduct of Joint Low Altitude Aircraft Survivability Quick Reaction Test (JLAAS QRT). He was director Joint Global Positioning System Combat Effectiveness (JGPSCE) Joint Test and Evaluation (JT&E), Kirtland AFB, New Mexico. Prior to JGPSCE JT&E director Colonel Jencik was deputy director of operations, Headquarters Air Force Operational Test and Evaluation Center (AFOTEC), Kirtland AFB, New Mexico. He was responsible for the conduct of Air Force operational testing of aircraft, weapons, command, control, and communications, and space systems. The directorate guided the initial planning, operational execution, and reporting of five detachments and numerous operating locations. He was assigned to AFOTEC from the Chief of Staff, Joint Task Force-Southwest Asia, Prince Sultan AFB, Saudi Arabia. Colonel Jencik led and directed efforts of 650-person, multi-national staff providing personnel, intelligence, operations, logistics, force protection, communications, and legal support to the United States' two largest contingencies, Operations SOUTHERN WATCH and ENDURING FREEDOM. He recieved his BS in electrical engineering from Stevens Institute of Technology, Hoboken, New Jersey, in 1977. He recieved his Masters in systems and control engineering from the University of West Florida in 1990. The colonel has across-the-board experience in operational testing including field-testing, program identification and test concept developments director, and rapid test and evaluation. He is a command pilot in the F–4. His professional expertise is in electronic warfare and operational test and evaluation.

Mr. William Herman received his BS in Electrical Engineering from New Mexico State University and his MS in Electrical Engineering from Purdue University. Mr. Herman is currently the Technical Director of the Air Force Joint Test and Evaluation Group located at Kirtland AFB in Albuquerque, New Mexico. The AFJTEG supports the Director, Operational Test and Evaluation's Quick Reaction Test program, which is part of the Joint Test and Evaluation program. Mr. Herman is responsible for all technical aspects of QRT planning, execution, and reporting, including test designs, test plans, data management and analysis plans, and test product planning and development. He has worked for the federal government for eight years; during that time he has been the Technical Director for several JT&E programs, including the Joint Battle Damage Assessment JT&E, the Joint Warfighters JT&E, and the Joint Suppression of Enemy Air Defenses JT&E. In addition, he was the Technical Director for the first QRT performed by the Director, Operational Test and Evaluation, Joint Test and Evaluation program, Joint Survivability (JSURV). Mr. Herman previously worked for Science Applications International Corporation where he was the Chief Engineer on the Joint Camouflage Concealment, and Deception JT&E. He may be reached by email at bill.herman@afotec.af.mil.

Mr. Gregory J. Czarnecki, biography can be found on page 17.

JLAAS is sponsored by the US Central Command based on a desire to reduce the risk of airfield operations in Iraq. The lead Operational Test Agency (OTA) for JLAAS is the Air Force Operational Test and Evaluation Center (AFOTEC). Supporting OTA functions are provided by the Army Test and Evaluation Command (ATEC). The JLAAS test concept was co-developed by the Joint Aircraft Survivability Program (JASP) and is being managed, planned, and executed by the Air Force Joint Test and Evaluation Group (AFJTEG) located at Kirtland AFB. The US Army, Air Force, Navy, Marine Corps, and US Central Command (USCENTCOM) are designated as participating Services and commands.

Calendar of Events

JUL

10–13, Tuscan, AZ
41st AIAA/ASME/SAE/ASWW Joint Propulsion Conference and Expo
www.aiaa.org

18–22, Long Beach, CA
Defense Systems Acquisition Management Course
cohara@ndia.org

26–28, WPAFB, OH
Aircraft Combat Survivability Short Course
http://jsa.jcs.mil
darnell.marbury@navy.mil

AUG

1–4, St. Louis, MO
2005 Tri-Service Infrastructure Systems Conference and Expo
www.aiaa.org

15–18, San Fricisco, CA
AIAA Guidanse, Navigation, and Control, Atmospheric Flight Modeling and Simulation Technologies, 3rd Inter Conversion Engineering Conference
www.aiaa.org

25–25 San Antonio, TX
2nd Sustainable Range Management
www.rangecon.org

30 Aug–1 Sep, Long Beach, CA
Space 2005 Expanding the Envelope
lisab@aiaa.org

SEP

12–15, New London
2005 Joint Undersea Warfare Technology Conference
kwilliams@ndia.org

19–23, New Orleans, LA
Defense Systems Acquisition Course
cbuck@ndia.org

20-22, Nellis AFB, NV
Joint Aircraft Survivability Program Review
Darnell Marbury: 703.607.3509x10, or
darnell.marbury@navy.mil

Information for inclusion in the Calendar of Events may be sent to:

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